Larynx Adaptation From Unamplified To Amplified Singing

Ingo Titze

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Adaptation is a short-term change to conform to a new habitat, environment, or social conditions. It is not the same as evolution, which is a long-term change in genetics for survival of a species. With physical exercise, the body can adapt in a time frame of a few days to a few months. We can adapt by simply changing our behavior with the given physiology and anatomy. Further adaptation can occur with increased strength of muscles, connective tissue, and cognitive ability. To the contrary, evolutionary changes that are passed on genetically to future generations can require thousands to millions of years, especially if survival is not threatened.

How well is the larynx suited to adaptation? One adaptation has already taken place for all of us and our ancestors over the last 50,000 years or so. Because the primary means of communication became speech, assisted by memory and travel for messaging, calling or shouting over long distances has become largely obsolete. As detailed in a previous publication, the laryngeal anatomy (framework and musculature) was well suited for high and loud vocalization prior to modern speech.[1] With adaptation to rapid speech articulation, low fundamental frequency and low intensity became more effective. Low fundamental frequency and low intensity are favorable acoustic adaptations to high information transfer, that is, many vowels and consonants delivered rapidly. Low fundamental frequency increases the density of sound source frequencies that excite the resonators, which provides articulatory clarity. Low intensity allows a balance between voiced and unvoiced phonemes. This adaptation to speech has required some muscular adaptation. For example, vocal fold length for speech does not allow optimal sarcomere muscle length for cricothyroid and thyroarytenoid muscles.[2] Vocal folds are mostly shortened when adducted for speech. There appears to be no evidence that structural or genetic changes have taken place to optimize the musculature for a bias toward shortened vocal folds.

Crying, shouting, outdoor calling, and singing have been exceptions to the trend toward low f_o and low SPL. A long distance outdoor calling study showed that single word intelligibility does not carry more than about 100 meters, partly because f_o is always raised high and unvoiced consonants do not carry well at all in free space.[3]

In the last century, technological innovations have resulted in a further adaptation of the larynx. Electronic enhancement and amplification are changing the acoustic delivery again. In traditional unamplified singing (which is

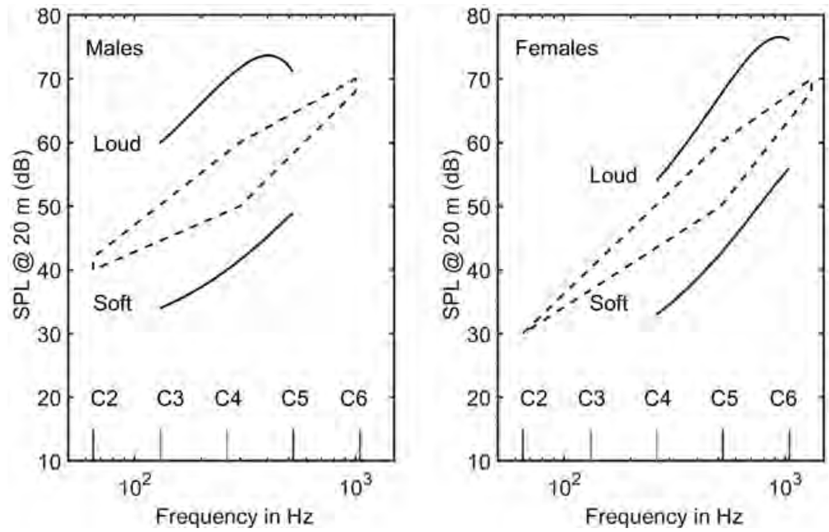

Figure 1. Voice range profiles for males and females. Solid lines are from classically trained college students (unamplified) and dashed lines are predicted adaptations for microphone-trained singers (after Ingo R. Titze and Lynn Maxfield, "Adapting the Voice Range Profile for Singers to Include Duration of Voicing," *Journal of Singing* 77, no. 5 [May/June 2021]: 653–661).

still preserved), several perceived levels of loudness are desirable, and in some cases required in vocal scores—*pp p mp mf f ff*. To make these levels distinct to the listener in a concert hall, they require at least 3 dB increments between the dynamic markings (2 dB is a just noticeable difference in free-field listening). That means that singers need to have at least a 15 dB intensity range for most of the notes they sing. Various strategies for loudness variation are employed with vocal fold and vocal tract adjustments in unamplified classical singing, Forexample, boosting the sound energy in the 2500—3300 Hz range with a singer's formant cluster makes use of the highest auditory sensitivity of the listener.

Typical voice range profiles (VRPs) for classically trained singers are shown in solid lines in Figure 1, males on the left and females on the right. These profiles were obtained from college-level singers (five for each sex). Only a two-octave range is shown (C_3—C_5 for males and C_4—C_6 for females) because they were able to maintain a 20–25 dB SPL ranges in these two octaves. The SPL range diminished at both ends of this pitch range. Superimposed on the figures (in dashed lines) are expected adaptation (not yet measured) for singers who count on microphone assistance. A dynamic range of 20 dB or more is not expected on any note, but the pitch range is expanded to be about 4 octaves for some singers. That appears to be the logical progression with electronic assistance—a trade-off between dynamic range and frequency range. Growling and vocal fry extend the low end while mixed registration and whistle voice can extend the high end. The larynx adapts with more range of motion between cartilages to vary vocal fold length or to strengthen the vocal ligament.

There will also be a differential adaptation between hand-held microphone use and head-mounted microphone use. Both intensity and tone color (frequency balance) can be adjusted liberally by the performer with hand-held microphone use. On the musical theatre stage, some of the control is left to the audio technician. The singer and the technician share the responsibility of loudness and timbre (tone color) adjustment.

A further adaptation is expected for vocal endurance and the associated variable known as vocal fatigue. A beginning damage-risk criterion has been proposed on the basis of accumulated speaking time of classroom school teachers.[4] The acoustic variables were fundamental frequency and sound pressure level. The risk criterion is illustrated in Figure 2. As an example, loud speech (90 dB @ 30 cm mouth to microphone distance) at a fundamental frequency of 200 Hz should be limited to 3 hours or less. At 80 dB, this increases to 5–7 hours, and at 70 dB as much as 10–15 hours may be safe. The predictions are based on self-assessment of fatigue by the teachers. It is not yet clear how this applies to singing.

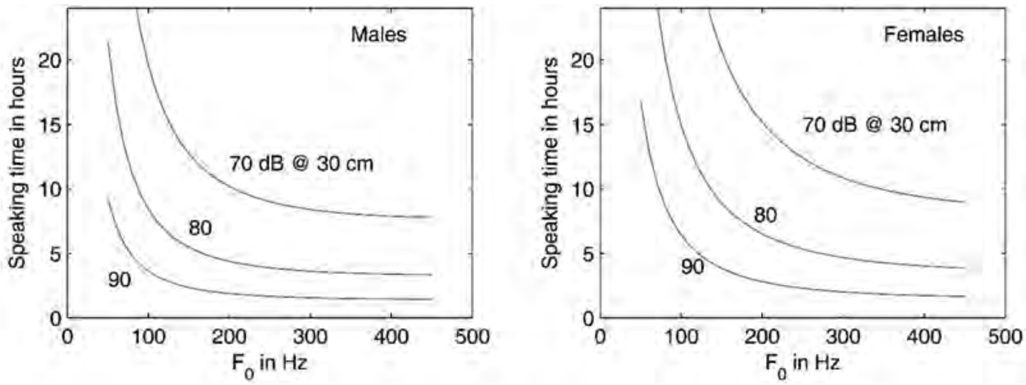

Figure 2. Boundary curves for damage risk from vocal fold collision for prolonged speaking time. Parameters are mean fundamental frequency (horizontal axis) and sound pressure level (SPL) for three separate curves. Below the curves is expected to be safe, above the curves is expected to be risky (after Titze and Hunter, 2015).

It is argued above that a higher fundamental frequency is healthier for the laryngeal musculature, yet a higher fundamental frequency produces more vocal fold collisions. The adaptation is a balance between keeping the laryngeal musculature at its peak performance and keeping the vibrating tissue from becoming traumatized with excessive mechanical stress.

The biggest unknown is the expected adaptation of the larynx (and surrounding structures) to vocal tone quality changes that cannot be produced or added electronically. Whatever cannot be regulated by autotuning, spectral balancing, noise addition, and feedback to the singer over headphones will become a new challenge for the innovative artist. Multiphonics, the simultaneous use of several sound sources along the airway, is a new dominant trend. Now the adaptation is not only laryngeal, but the entire airway musculature and tissue construct must reach a new configuration. Lung pressure must be distributed and shared across multiple tissues in vibration. Some of these tissues (e.g., false folds, aryepiglottic folds, tip of the epiglottis, velum) have not been exposed to prolonged vibration. Endurance with these modalities is yet an unknown.

NOTES

1. I. R. Titze, “Human Speech: A Restricted Use of the Mammalian Larynx,” *Journal of Voice* 31, no. 2 (March 2016): 135–141.
2. Ibid.
3. I. R. Titze, D. Blake, and J. Wodzak, “Intelligibility of Long Distance Emergency Calling,” *Journal of Voice*, September 15, 2018. pii:S0892–1997(18)30172–2; doi: 10.1016.j.jvoice.2018.08.008 [epub ahead of print].
4. I. R. Titze and E. J. Hunter, “Comparison of Vocal Vibration Dose Measures for Potential Damage Risk Criteria,” *Journal of Speech Language Hearing Research* 58, no. 5 (October 2015): 1425–1439.

Dr. Ingo R. Titze has served as Founder and President of the National Center for Voice and Speech since 1990. His was a University of Iowa Foundation Distinguished Professor of Voice, Speech, and Vocal Music prior to retirement from Iowa in 2019.

He has published over 500 articles in scientific and educational journals. His book publications include *Principles of Voice Production* (1994), *The Myoelastic-Aerodynamic Theory of Phonation* (2006); in collaboration with Katherine Verdolini, *Vocology: The Science and Practice of Voice Habilitation* (2012); and *Fascinations with the Human Voice* (2010), which is printed in eight languages. His research interests include biomechanics of human tissues, acoustic phonetics, speech science, voice disorders, professional voice production, and the computer simulation of voice. His formal training is in Electrical Engineering (MS) and physics (PhD).

Dr. Titze is a founding member and first elected President of the Pan-American Vocology Association. Other professional affiliations include the Acoustical Society of America, The National Association of Teachers of Singing, the American Speech Language Hearing Association, and the American Laryngological Association. Honors include The Gould Award for outstanding research in laryngeal physiology (1984), the Silver Medal Award from the Acoustical Society of America (2007), the Honors of the Association from ASHA (2010), and the Sundberg-Titze Award from the Voice Foundation (2020). He has administered and taught in the Summer Vocology Institute, the premiere Vocology training program, for 20 years. He has been married to Kathy Titze for 52 years, with whom he has four children and nine grandchildren. He remains an active singer.