

How Well Does the Larynx “Canal” Match the Ear Canal?

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WHILE EVERYBODY IS FAMILIAR with their ear canal, nobody is able to identify or give a reference in the literature to a “larynx canal.” For many years, a laryngeal airway above the vocal folds has been labeled the larynx tube,¹ the epilaryngeal tube,² or simply the epilarynx.³ The word *canal*, however, may be an excellent descriptor because the geometry is rather complex and only partially tube-like. Figure 1 is a comparison of the two canals. On the left is shown a Magnetic Resonance image of a mid-sagittal cross-section through the vocal tract airway (black is air, gray is tissue); on the right, a sketch of the outer and middle ear is shown. The two canals are highlighted with dashed boxes and their mean dimensions given below.

Anatomically, the larynx canal is the combination of the ventricle, the ventricular fold glottis, and the laryngeal vestibule (Figure 2, now shown in coronal view). The similarity between the larynx canal and the ear canal in terms of their acoustic functions has only recently been discussed.⁴ This airway above the vocal folds has a remarkable acoustic reciprocity with the airway leading to the ear drum, the outer ear, and the ear canal. The reciprocity seems logical, given that sound is produced with vibrating tissue (the vocal folds), guided into free airspace by the vocal tract, and gathered by the listener back from free airspace into the ear canal and then to the inner ear with tissue vibration (the ear drum).

Consider a comparison between the airway dimensions of the vocal tract and the outer ear. The average length of an adult human ear canal is 2.5 cm, about the same length as the larynx canal, or the epilarynx tube.⁵ The cross-sectional area of the ear canal is 0.62 cm², while the mean cross-sectional area of the larynx canal across both sexes is 0.5 cm².⁶ The acoustic impedance of the ear canal (without reflections) is

$$z = \rho c / A$$

where ρ is the air density, c is the speed of sound, and A is the cross-sectional area. The calculation yields 64 g / (s cm⁴). In comparison, the same calculation on the larynx canal yields 80 g / (s cm⁴), a similar value. The impedance of the ear drum is highly variable with frequency, with a mid-range value of about 300 g / (s cm⁴).⁷ By comparison, the glottal impedance, also highly variable with glottal adduction, has a mid-range value of about 50 g / (s cm⁴).⁸ It must be pointed out, however, that there is no fluid flow through the ear

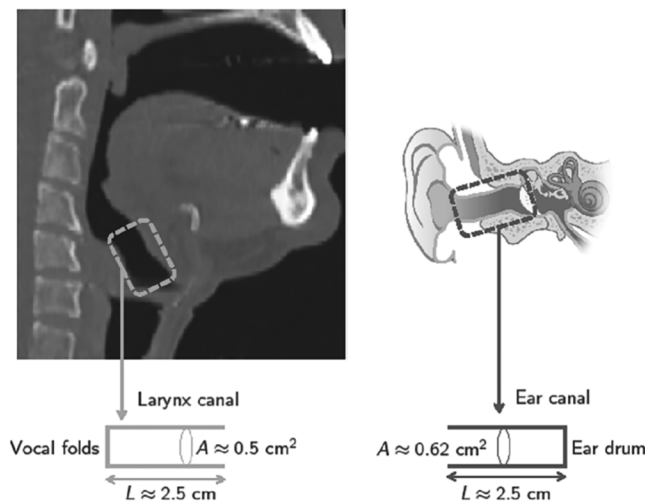


Figure 1. Anatomy of the ear canal and the larynx canal. Left image from B. H. Story et al., “The Relationship of the Vocal Tract to Three Voice Qualities,” *The Journal of the Acoustical Society of America* 109, no. 4 (May, 2001): 1651–1667. Right image from J. Hoit, G. Weismer, and B. Story, *Foundations of Speech and Hearing Science: Anatomy and Physiology* (New York: Plural Publishing, 2021).

drum. The acoustic airflow is only a displacement flow of the ear drum tissue, which makes the impedance (the pressure-flow ratio) larger by a factor of about six. Additionally, because both the ear and larynx canals can be considered closed at one end (eardrum and glottis, respectively) and open at the other (free space and widened lower pharynx, respectively), the resonance frequencies of each would be nearly the same, depending on the overall shape of the canals. However, there seems to be an adaptation in the dimensions of the larynx canal, beginning at birth and progressing with gender and age. Adult female larynx canals are about 1.6 cm long and have cross-sectional area of 0.25–0.35 cm². For children, these dimensions would be even smaller. It would be fruitful to investigate whether these adaptations are for the purpose of an impedance match for maximum power transfer or maximum speech intelligibility for the given age and gender.

In humans, the outer ear (the pinna) is made of ridged cartilage covered by skin. It is not tubular, but shell-like. In other species, the pinna is partially tube-like, mirroring at least a part of an expanding vocal tract. Sound funnels through the pinna into the ear canal, the tube that ends at the eardrum (known as the tympanic membrane). Some nonhuman species, for example, long-

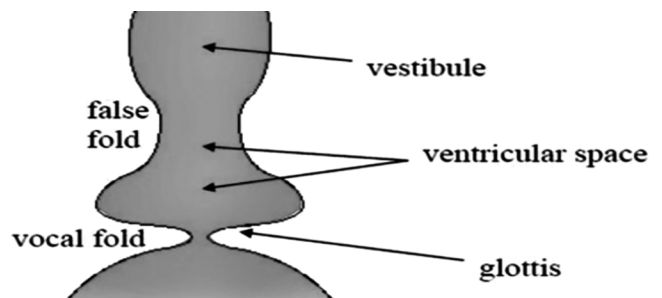


Figure 2. Sketch of coronal section through the larynx canal. From I. R. Titze and K. Verdolini Abbott, *Vocology: The Science and Practice of Voice Habilitation* (Salt Lake City: National Center for Voice and Speech, 2012).

eared gerboas and mule deer, have pinnae comparable in length to their vocal tract lengths. Figure 3 shows the mule deer pinnae. Directivity of the received sound is optimized with a semicircular open channel rather than a completely closed tube. Animals have developed the musculature to rotate their ears in multiple directions. The average length of mule deer ears is about 50 cm, comparable to its vocal tract length.



Figure 3. Outer ears of a mule deer. Courtesy Joshua Kraemer, by permission.

The early acoustic hearing aids were trumpet-like, gathering the sound with a horn and gradually reducing the cross-sectional area to approximate the diameter of the ear canal (Figure 4). Some directivity was achieved by manually rotating the horn. The length of the horn was variable, in some cases being as large as a megaphone used by cheerleaders. The larger the distal opening, the more sound can be gathered. As with the vocal tract, sudden changes in the cross-sectional area produce standing waves, which would make the reception frequency-dependent.

This brief essay on the comparison between the ear canal and the larynx canal has shown that impedance matches exist not only between the source and the transmission system, but also between the entire production and the reception systems. For today’s human vocalizations, the dynamic nature of the laryngopharynx for speech and singing makes the quantitative comparison to the static nature of the external ear canal more inter-



Figure 4. Ear trumpet used as an acoustic hearing aid. From K. D. Decker, “Non-electric hearing aids outperform modern devices,” *No Tech Magazine* (August 24, 2017); <https://www.notechmagazine.com/2017/08/non-electric-hearing-aids-outperform-modern-devices.html> (accessed September 23, 2021).

esting. The vocal tract configuration is variable from moment to moment, also adapting to breathing and swallowing, but one wonders if primal outdoor calling thousands of years ago, or infant cry vocalizations, may have targeted matching configurations. More research appears to be forthcoming on this topic.

NOTES

1. J. Sundberg, “Articulatory Interpretation of the Singing Formant,” *Journal of the Acoustical Society of America* 55, no. 4 (April 1974): 838.
2. I. R. Titze and B. Story, “Acoustic Interactions of the Voice Source with the Lower Vocal Tract,” *Journal of the Acoustical Society of America* 101, no. 4 (May 1997): 2234–2243.
3. B. H. Story, “The Vocal Tract in Singing,” in G. Welch, D. Howard, and J. Nix, eds., *The Oxford Handbook of Singing* (New York: Oxford University Press, 2016), Chapter 7.
4. I. R. Titze and K. Verdolini Abbott, *Vocology: The Science and Practice of Voice Habilitation* (Salt Lake City: National Center for Voice and Speech, 2012).
5. B. H. Story, I. R. Titze, and E. A. Hoffman, “Vocal Tract Area Functions from Magnetic Resonance Imaging,” *The Journal of the Acoustical Society of America* 100, no. 1 (July 1996): 537–554. B. H. Story, I. R. Titze, and E. A. Hoffman, “The Relationship of Vocal Tract Shape to Three Voice Qualities,”

The Journal of the Acoustical Society of America 109, no. 4 (May 2001): 1651–1667.

6. Ibid.
7. R. H. Withnell and L. E. Gowdy, “An Analysis of the Acoustic Input Impedance of the Ear,” *Journal of the Association for Research in Otolaryngology* 14, no. 5 (October 2013): 611–622.
8. R. Konnai, R. C. Sherer, A. Peplinski, and K. Ryan, “Whisper and Phonation: Aerodynamic Comparisons across Adduction and Loudness,” *Journal of Voice* 31, no. 6 (November 2017): 773e11.

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Lightly come or lightly go:
Though thy heart presage thee woe,
Vales and many a wasted sun,
Oread let thy laughter run,
Till the irreverent mountain air
Ripple all thy flying hair.

Lightly, lightly—ever so:
Clouds that wrap the vales below
At the hour of evenstar
Lowliest attendants are;
Love and laughter song-confessed
When the heart is heaviest.

James Joyce, “Lightly Come or Lightly Go”