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Confusion Continues to Exist about the Bernoulli Effect in Vocal Fold Vibration

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Journal of Singing, January/February 2019
Volume 75, No. 3, pp. 309–310

THERE ARE A FEW EXPLANATIONS in voice science that continue to live on in spite of repeated evidence to the contrary. One of these is the explanation of how vocal folds can sustain their vibration over repeated cycles with energy supplied by the glottal airstream. The explanation goes something like this: *the subglottal pressure pushes the vocal folds apart, then the elastic recoil force in the tissue stops the outward motion and reverses it, and then a negative Bernoulli pressure sucks them together; the result is a push and a pull in every cycle, sustaining the vibration.* It has taken years for pedagogues and scholarly writers to include two critical conditions that are absolutely necessary in this explanation: (1) there must be non-uniform movement between upper and lower portions of the folds; and (2) there must be inertance of the vocal tract air column above the vocal folds. Without one of these conditions, the Bernoulli energy law does not predict any energy transfer from glottal airflow to vocal fold tissue. Hence, vibration cannot be self-sustained.

Let me take this explanation one step at a time. For energy to be transferred to an oscillating system (the vocal folds), there must be a net positive force in the direction of movement during the cycle. This force can be supplied in a continuous fashion or in bursts. The energy transferred into the system per cycle must be at least as great as the energy dissipated by friction or other losses if oscillation is to be sustained. Given that the direction of movement always changes in an oscillating system (outward movement changes to inward movement), *an aerodynamic force that is not direction sensitive or cannot change with direction of movement is useless.* The same force would be applied for outward movement as for inward movement, causing a complete cancellation of the energy supplied to the system. This is exactly what we would get from Bernoulli forces applied to the vocal folds without one of the conditions stated above. The Bernoulli energy law predicts aerodynamic forces on the basis of vocal fold position and glottal shape only, not direction of movement. Thus, if shape does not change, Bernoulli forces alone cannot transfer energy. Unless the glottal shape or the airway environment can change with direction of movement, all Bernoulli forces cancel out to a net zero.

Now consider Condition 1, non-uniform tissue movement. If the movement of the top of the vocal folds lags behind the movement of the bottom, there will be a convergent glottis (convergent from bottom to top) for outward movement and a divergent glottis for inward movement. Bernoulli forces are sensitive to these shape changes. Pressures are lower in a divergent glottis than in a convergent glottis. With this shape change, the Bernoulli forces become sensitive to direction of movement and hence can impart energy to the vocal folds. However, the tissue must offer a natural mode of vibration that allows alternate convergent and divergent shapes.

Condition 2, an inertive supraglottal vocal tract air column, can also produce a direction-dependent force on the vocal folds. For outward movement, an increasing glottal airflow produces a positive pressure directly above the glottis. This is the pressure needed to compress and accelerate the air column in a forward direction in the vocal tract. The pressure is also felt in the upper part of the glottis and helps to push the vocal folds apart. For inward movement of the vocal folds, a decreasing glottal airflow reduces the pressure directly above the glottis. In fact, a negative pressure is produced in the wake of an air column that continues to move forward due to its inertia (quantified as acoustic inertance). This negative pressure is also felt in the upper part of the glottis and pulls the vocal folds toward each other.

In summary, only direction-dependent forces can transfer energy from the airstream to the vocal folds. While Bernoulli's law applies to airflow and air pressures in the glottis, the direction-dependence must be provided by conditions not describable by Bernoulli's law alone. Some figures and a little mathematics are available in Chapter 4 of my book.[1]

NOTE

1. Ingo R. Titze, *Principles of Voice Production* (Salt Lake City, UT: National Center for Voice and Speech, 2000).