Physiology of Voice Production:

Considerations for the Vocal Performer

Yolanda D. Heman-Ackah, MD

Department of Otolaryngology-Head and Neck Surgery

Graduate Hospital and

Thomas Jefferson University

Philadelphia, PA

Running Head: Voice Physiology

Please address all correspondence to:

Yolanda D. Heman-Ackah ,MD
1721 Pine Street
Philadelphia, PA 19103

The larynx is the primary organ involved in voice production. However, phonation requires a complex interaction between many bodily systems to achieve the sound that we associate with the voice.

Mechanics of Voice Production

Production of the voice involves the same biophysics as the mechanics of sound production from any source. The production of sound requires four main components: airflow, an oscillator, a resonator, and an amplifier. In voice production, the source of airflow is the lungs. The abdominal muscles, chest, and back contribute to airflow in voice production. The oscillator is the vocal folds, which vibrate and place the air from the lungs into a wave-like motion. The resonance chamber and amplifier are composed of the remainder of the vocal tract: the supraglottic (above the vocal folds) larynx, the pharynx, the oral cavity including the tongue and palate, the nasal cavity, the sinuses, and the head.

Sound Source

The sound source for voice production is the larynx and the vibrating vocal folds. The vocal folds themselves are made of five layers of tissue. The deepest layer is the muscle of the vocal fold, termed the vocalis or thyroarytenoid muscle. Next to the vocalis are the deep and intermediate layers of the lamina propria, which form the vocal ligament. Overlying the middle layer is the superficial layer of lamina propria, which is a gelatinous matrix that permits the last layer, the epithelium, to glide over the vocal ligament (the intermediate and deep layers) during phonation.[1] When one makes the decision to talk, the vocal folds come together in the midline. Air is forced from the lungs against the closed vocal folds, forcing them to separate. The epithelium of the vocal folds glides, over the superficial layer of lamina propria. As they open, air travels past the vocal folds and into the upper parts of the larynx and into the pharynx. When the vocal folds snap shut, sound is produced.[2] The frequency of opening and closing of the vocal folds determines the frequency of the sound waves, and, thus, the pitch of the voice. The frequency of vibration of the vocal folds is termed the fundamental frequency, and the character of the sound that is produced from the vocal folds is very similar to the sound that is produced from buzzing lips.[3] This sound is then modified by the resonance chamber of the vocal tract and produces the voice that gives each person his or her characteristic vocal signature.[4]

A louder sound can be produced by one of two methods: by increasing the airflow from the lungs or by increasing glottal resistance. The preferred method of increasing volume utilizes a combination of both strategies. Greater force in the air stream from the lungs, exerted against somewhat increased adductory (closing) force, causes the epithelium of the vocal folds to open wider as air is forced past them. A wider excursion produces a louder sound when the vocal folds clap together. When less airflow is used from the lungs, the vocal folds are blown apart to a lesser degree and a softer sound is produced. Clapping the hands can mimic this effect (although buzzing lips are actually more analogous). When the hands are wide apart at the start of each clap, a louder sound is produced. When the hands are closer together at the start of each clap, a softer sound is produced. The vocal folds function in a similar fashion. To raise the volume primarily by increasing the glottal resistance, the individual forcefully closes the vocal folds. Oftentimes, doing so involves recruiting the accessory muscles of phonation, including the pharyngeal constrictors, the strap muscles in the neck, and the base of the tongue, as well as using the vocal folds themselves. Such use of excess force is termed laryngeal hyperfunction, and the forceful closure of the vocal folds can cause vocal fold trauma and result in vocal fold tears, hemorrhages, edema (swelling), or masses such as nodules, polyps or cysts. So, optimal balance between airflow forces and glottal resistance is essential.

If there is a small space between the vocal folds, as can be caused by a mild vocal fold paresis (weakness), vocal fold masses (such as a polyp, nodule, or cyst), vocal fold scar, or vocal fold swelling, then there may be escape of air throughout the phonatory cycle, and the epithelium of the vocal folds may be unable to close completely. Thus, the same degree of effort from the lungs produces a softer sounding voice. This can be demonstrated by more or less cupping the hands in a C-shaped fashion so that when the hands are clapped together, there is always a space between the palms. If the hands open with the same degree of excursion as they did uncupped, a softer clap is produced. To produce the same loudness of clapping with the hands cupped as with them uncupped, the cupped hands need to have a wider excursion with each clap than do the uncupped hands. From a voice perspective, this translates into a greater requirement for increased airflow from the lungs when a gap exists between the vocal folds than is needed when the vocal folds are perfectly symmetric and meet in the midline. From a functional perspective, incomplete vocal fold closure means that more energy is needed to produce greater airflow from the lungs to increase volume and projection and to sustain phonation, which creates a greater susceptibility to fatigue. Many people with incomplete glottic closure subconsciously compensate by recruiting the accessory muscles of phonation, and then begin to suffer the consequences of laryngeal hyperfunction, as well as those associated with incomplete closure. This pattern leads to voice fatigue, and sometimes to serious vocal fold injury.

Resonance and Amplification

The resonance chamber and amplifier of the voice is the vocal tract, which includes the back of the throat (pharynx), the tongue, the palate, the mouth, the back of the nose (nasopharynx), and to a lesser degree, the sinuses and the head. As sound leaves the vocal folds, the waves bounce back and forth against the walls of the vocal tract. As the sound resonates throughout the vocal tract, it gains energy in those areas that are amplified by the particular shape of the vocal tract and loses energy in those areas that are dampened by the shape of the vocal tract.[4] Because everyone's pharynx, oral cavity, nasopharynx, and head are shaped differently, amplification of the fundamental frequency occurs at different sites and to different degrees from one person to another. The harmonic frequencies with the highest energy are termed the "formant" frequencies.[4] The harmonic frequencies are responsible for giving each voice it's own "signature" sound that allows us to distinguish one individual from another. The formant frequencies give the voice its "ring", which allows the voice to be heard even in the presence of a significant degree of background noise.[4] Changing the shape of the vocal tract by altering the position of the tongue, the shape of the pharynx, and the position of the uvula changes the characteristics of the harmonics and formants, and thus, the projection achieved.[4]

Amplification of the voice occurs primarily in the oral cavity, which has a megaphone-like effect on vocal projection. In general, a more open mouth and oral cavity causes greater amplification of the voice. This is achieved best by optimizing the position of the tongue and its base, the palate, the mandible and the lips. Elongation and widening of the vocal tract includes several conscious mechanisms, including maintaining correct neck posture. If the neck is tilted back or the chin is lifted too high, a bend is created in the pharyngeal area, which effectively narrows the resonance and amplifying chamber at the region of the tongue base. Ideally, the head should be in the neutral position so that the spine is straight through the skull base.[4] This produces a straighter vocal tract and usually enhances resonance and projection. Elevation of the uvula and the palate helps to open the vocal tract in the back of the oral cavity and seals the nasopharynx to minimize hypernasality. Relaxation of the tongue base, with the tip of the tongue placed in a more forward (but relaxed) position, helps to lengthen the oral cavity and widen the space at the tongue base, creating a longer, greater diameter amplifier.[4]

Airflow and Breathing

Airflow for vocal production involves a complex interplay between the lungs, the abdomen, the chest, the back, the legs and hips, as well as other structures.

The Lungs

The lungs have the ability to expand in all three dimensions, with the greatest area for excursion being down. The lungs are housed within the chest cavity, are separated from the abdomen by the diaphragm, and are encased on all sides by the ribs. The ribs limit the amount of outward expansion of the lungs, leaving the greatest room for expansion down, into the abdomen.[5] The diaphragm contracts (moves down) with inhalation, and relaxes (moves up) with exhalation.[6] As the diaphragm contracts with inhalation, the abdominal contents are pushed downward and outward to allow room for the expanding lungs. Diaphragm contraction increases the negative pressure in the chest, creating a suction effect. As the abdominal muscles relax and the diaphragm contracts toward the abdomen, more air is siphoned into the lungs with the inhalation. During normal, resting state respiration, exhalation is passive.[6] The diaphragm relaxes as air is released from the lungs. With active exhalation, the abdominal muscles contract, and the diaphragm relaxes as air is forced out of the lungs.[6] Larger and consciously controlled breaths employ both the diaphragm and abdomen for inspiration and rapid, shallow breaths use diaphragmatic breathing almost exclusively. In voice production, a greater control of airflow, and thus the voice, can be achieved with abdominal breathing patterns than with passive breathing alone.

The abdominal region provides the greatest room for expansion of the lungs. The lungs consist of two halves, the right and the left. The right lung is divided further into three lobes, while the left lung is divided into two lobes only. Each lobe functions much like a balloon, expanding when air enters during inhalation and shrinking when air leaves during exhalation.[6] Like balloons, the lobes of the lung have a certain degree of elasticity, which allows this expansion and recoil. The lower lobes of the lungs have the greatest capacity for greatest volume, and also have the greatest compliance, which allows for greater expansion into the abdomen.[6] The ribs surround the top lobes of the lungs, thus, limiting their ability to expand and recoil. The positioning of the collarbones and the scapulae (the shoulder blades) also limits the expansion of the lungs. The optimal position for expansion is with both the collarbones and the scapulae flat, down, and maximally expanded horizontally, to allow for maximal pulmonary expansion and filling.

Lung function can be limited further by obstructive lung diseases such as asthma and chronic obstructive pulmonary disease (from smoking). In such cases, the lungs are able to inhale the same amount of air; however, the force produced on exhalation is decreased due to limited recoil within the lungs. Restrictive lung diseases, such as emphysema, obesity, and the effects of broken ribs, limit the amount of air the lungs can inhale, and thus, the amount of air the lungs can exhale. Each of these then affects airflow and control during voice production, and impairments can predispose to vocal fatigue and decreased vocal projection.

The Abdomen

The abdomen contributes to breathing by helping to produce a suction effect on the diaphragm and lungs. The abdomen consists of several layers of muscles: the external oblique, the internal oblique, the transverse abdominus, and the rectus abdominus muscles. The external oblique muscles lie immediately beneath the skin and fat. They insert into, and obtain their strength during contraction from, a central, dense layer of tissue (the fascial insertion). The internal oblique muscles lie beneath the external obliques and run horizontally along the side of the abdomen. Much of the abdominal contribution to breathing is from the internal and external obliques.[7] The rectus abdominus muscles lie in the center of the abdomen with their fibers running vertically. The rectus abdominus muscle bends the torso when it contracts. Its main function is to support the back and to assist with balance; it does not contribute much to breathing. Under the internal oblique muscles lie the transverse abdominal muscles, which contribute little to breathing and breath support, and more to core strengthening. Abdominal support with exhalation helps to increase the suction effect on the diaphragm, resulting in a greater amount of air entering the lungs. Sustained contraction of the abdomen during exhalation helps to regulate the flow of air from the lungs during breathing and phonation.

Knowledge of the abdominal anatomy and musculature is critical for the voice professional who is considering abdominal surgery. Surgery on the abdomen weakens the muscles that are cut. Rehabilitation and strengthening of the weakened abdominal muscles prior to resuming a normal vocal routine is imperative for the professional voice user.

The Back

The back consists of five to six layers of muscles whose fibers cross each other. The main function of the back is to help maintain balance and to serve as a support for the abdomen. Abdominal support of breathing requires the support of the back muscles to maximize the force of any given abdominal contractile effort. If firm support from the back occurs simultaneously with pressure from the abdomen, a greater force is created.

The Effects of Posture, Balance, Stance, and Emotions on Breathing and Voice Production

Shifts in posture and stance affect the position of one’s center of gravity, thus changing the actions of the muscles that are engaged actively in maintaining balance. For optimal breathing and voice production, posture and stance should be positioned to limit sway and contraction of the torso muscles of the back and abdomen, with the primary responsibility for balance falling on the leg muscles. Ideally, this involves standing with the feet flat on the floor with the weight forward over the metatarsal heads (balls of the feet), shoulder width apart, knees slightly bent, and torso erect and lifted. This results in a stable stance with the center of gravity residing at about the center of the pelvis. Standing with the feet together and knees straight shifts the center of gravity upwards, and the back and abdominal muscles become more actively involved in maintaining balance. Keeping the center of gravity low frees the back and abdominal muscles to be used more effectively in breath support. In doing so, this allows the abdomen and back muscles to be used primarily for breathing and breath support. This is the principle behind many of the different acting, singing, and dance techniques and exercises for posture and breathing.

Dizziness and imbalance secondary to medications, alcohol, drugs, neuropathies, inner ear disease, and visual dysfunction result in excessive engagement of the back and abdominal muscles to help maintain balance, thus lessening the use of these muscles for breath support. Anxiety, fear, grief, and other emotions involve tension of many of the muscles in the back and the abdomen and also alter the breathing pattern, which can affect the ability to control and provide sufficient breath support during vocal performance.

Summary

Voice production is the summation of the interplay between airflow, oscillation, resonance, and amplification. Many organ systems in the body participate actively in phonation in addition to the larynx, and each has a vital role. In fact, it is possible to produce a voice without a larynx, as is often demonstrated by individuals who have had the larynx removed and in whom other parts of the vocal tract take on the role of oscillator. Acquiring knowledge of the physiology of voice production, as well as of the anatomy of the organs that contribute to voice production, is the first step in understanding how to care for and maintain the voice throughout one’s professional career.

References

1. Hirano M. Structure and vibratory pattern of the vocal folds. In: Sawashima N, Cooper FS, eds. *Dynamic Aspects of Speech Production.* Tokyo: University of Tokyo Press, 1977: 13 – 27.
2. Sataloff RT. Clinical Anatomy and Physiology of the Voice. In: Sataloff RT, *Professional Voice: The Science and Art of Clinical Care,2nd edition.* San Diego: Singular Publishing Group, Inc. (1997):111 – 130.
3. Sundberg J. The acoustics of the singing voice. *Scientific American* 236 (1977):82 – 91.
4. Sundberg J. Vocal Tract Resonance. In: Sataloff RT, ed. *Professional Voice: Thescience and Art of Clinical Care,2nd edition.* San Diego: Singular Publishing Group, Inc. (1997):167 – 184.
5. Gould WJ, Okamura H. Static lung volumes in singers. *Ann Otol Rhinol Laryngol* 82 (1973):89 – 95.
6. West JB. Mechanics of Breathing. In: Best and Taylor's Physiological Basis of Medical Practice, 11th edition. West JB, ed. Baltimore: Williams and Wilkins. (1985): 586 – 604.
7. Hixon TJ, Hoffman C. Chest wall shape during singing. In: Lawrence V, ed. *Transcripts of the Seventh Annual Symposium, Care of the Professional Voice.* New York: The Voice Foundation, 1 (1978): 9 – 10.