THE SINGING VOICE – MEDICAL AND ARTISTIC PERSPECTIVES

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ABSTRACT

This paper attempts to provide a medical and artistic perspective on the singing voice. It starts from the premise that physicians and singing teachers must share a common goal – understanding the concepts of physics and acoustics involved in voice production, the laws governing the functioning of the vocal tract and the principles that regulate muscle functioning and their adjustment to the phonation requirements and especially to the requirements of the singing voice. The present paper provides an overview of the current knowledge in the field of vocal tract anatomy, sound production mechanism and main characteristics of the sound. These scientific notions are presented in the context of their practical applicability related both to the improvement of phonation and to the maintenance of a healthy vocal tract, which is essential to the professional singing voice. With the same purpose are presented the basic rules of voice hygiene, which besides preventing voice disorders contribute to increased resilience and flexibility of the vocal tract. Given these arguments, the present paper attempts to discover the areas in which science and art can work together in order to refine this instrument, which is the human voice.

Keywords: singing voice, vocal tract anatomy, sound production mechanism, phonation

Introduction

Underlining the uniqueness of the human voice, over 2000 years ago Aristotle said: "Although nature has gifted us all with voices, correct singing is the result of art and study". The human voice is the most complex musical instrument and, like any other instrument, it must be handled by a master in order to produce an outstanding artistic performance. Unlike the other instruments with which one can see, feel or perceive how sounds are produced, the human voice is still a "mysterious" system, found inside the human body and whose exact functioning mechanism is still unclear.

The voice is an indispensable part of inter-human communication. It is like a mirror reflecting the health, age, emotional state and mood. We can also consider the voice as the most expressive instrument in the world.

Researchers, physicians and singing teachers alike must share a common goal – understanding the concepts of physics and acoustics involved in voice production, the laws governing the functioning of the vocal tract and the principles that regulate muscle functioning and their adjustment to the phonation requirements and especially to the requirements of the singing voice. It is also important to know the main rules of vocal hygiene in order to maintain the health and optimal functioning of the vocal tract. The more we know about voice and its functioning mechanisms, the safer its use. Given these arguments, we must discover the areas in which science and art can work together in order to refine this instrument that is the human voice.

To this purpose, a multidisciplinary team is required for the evaluation and guidance of the vocal professional. Apart from the singing teacher, the team should include a phoniatrist, a psychologist and a vocal therapist. It is only through the close cooperation between the members of this team that the singing voice will reach an outstanding performance, while maintaining a healthy vocal tract, for an optimal functioning [2].

The anatomy of the vocal tract

The human voice is essentially an instrument. By understanding the components of our own vocal instrument we can improve the strength, endurance, flexibility and expressiveness of our voice. Like any musical instrument, in order to produce sounds, the voice requires: a power source (breath), which provides the airflow, a vibrator (the vocal folds), which turns the air into sound and a resonator, which converts the sound into human voice. In addition, the human voice has a fourth component, i.e. the articulator, which converts the sound into words and other vocal gestures [11].

The singers' lungs provide a constant airflow that passes through the vocal folds and gives the power of the voice. The abdominal musculature is the so-called "support" of the singing voice, although singers generally talk about the diaphragm as a support mechanism. The diaphragm generates the inspiratory force, while the abdominal muscles are important in expiration. Therefore, the abdominal musculature requires considerable attention in vocal training. The purpose of the abdominal support is to maintain a constant and efficient power source and inspiratory-expiratory mechanism.

Expiratory muscles are not the only muscles involved in the formation of vocal tract airflow. The inspiratory muscles also play an essential role in the physiology of voice production, as regulators of the phonatory airflow. The diaphragm is co-activated by some performers during singing and contributes to the fine regulation of singing. In the singing voice, when producing a long, soft tone with a high lung volume, three of five singers use the diaphragm to reduce expiratory recoil forces [3]. In conclusion, it seems that the diaphragm plays a more significant role than is generally believed, with variations from singer to singer [1].

Correct and efficient singing is based on proper breath technique and cannot exist without it. This is unanimously accepted by singing teachers and singers alike. Many vocal difficulties are due to improper breathing, which is not recognized and corrected in time. Most singing teachers agree that besides articulation, breathing is the only active part in singing, therefore we can say that: "Good breathing is the foundation of good singing, both technically and artistically. What matters is not the

quantity, but rather the flexibility of breathing" [9]. Phrase, tone, resonance and expression, all ultimately depend on breathing. The primary respiratory difference between trained and untrained singers is not increased total lung capacity, as popularly assumed; rather, the trained singer learns to use a higher proportion of the air in the lungs, thereby decreasing residual volume and increasing respiratory efficiency [8].

The **vibrator** is represented by the vocal folds, located within the larynx. Vocal folds have an anterior-posterior orientation, being attached at the front to the inside surface of the anterior part of the thyroid cartilage or anterior commissure, and attached at the back to the arytenoid cartilages, or more exactly to the vocal apophysis thereof. Men and women have different vocal fold sizes: male vocal folds are about 22 cm in length and female ones are between 18 and 20 cm long. Mechanically, they actually act more like three layers consisting of:

1) "**cover"** – epithelium and Reinke's space

2) "**transition"** – intermediate and deep layers of the lamina propria.

3) "**body"** – the vocalis muscle [10].

Functionally, the various layers have different mechanical properties and act somewhat like ball bearings of different sizes in allowing the smooth shearing action necessary to proper vocal fold vibration. Reinke's space is a potential space between the vocal ligament and the overlying mucosa. It is an avascular space, with an essential role in the mechanisms of vibration and sliding motion of the vocal fold mucosa. Lamina propria is the space between the basement membrane and the vocalis muscle. It is composed of extracellular matrix. Elasticity and osmotic regulation of this space are extremely important for phonation. [15]

Hyaluronic acid is the main component of the extracellular matrix and plays an important role as a modulator of the cellular behaviour and function. It allows the flexibility and sliding motion of the mucosa over the vocal ligament and contributes to the effectiveness of laryngeal vibration [5]. It also has a role in tissue viscosity, shock absorption, exudation and tissue repair, thus reducing fibrosis and scarring. It maintains a level of viscosity that creates proper phonation and a level of rigidity that allows the accurate control of the fundamental frequency [5]. Thus, it can be concluded that the differences in the extracellular matrix are critical in the vibration mechanism of the vocal folds. The differences in the composition

of this area may account even for the differences between vocal performances [15]. A better understanding of the exact composition of this space can help in future in clinical practice, especially in the prevention of voice problems.

According to Butler's studies [4], the proportion of hyaluronic acid in Reinke's space in women is much lower than in men, which generates a higher fragility and explains the high prevalence of voice trauma in women.

Once the singer understands the **"cover-body"** theory of phonation, he/she will admit that the health and flexibility of the mucosa must be strengthened and maintained in order to achieve optimum voice results [6].

The resonant cavities – The pure laryngeal sound produced by the vibration of the vocal folds is in itself thin and weak, but as it passes through the natural resonators it becomes enhanced and enriched with resonance and timbre. The principal resonators are: pharyngeal cavity, oral cavity, nasal cavity, nasopharyngeal cavity and, according to some, chest cavity. Resonance increases when the throat is relaxed and the breath is free.

These structures can be compared with the tube of a brass instrument located between the mouthpiece (vocal folds) and the bell (lips). Like any tube, it has certain resonance frequencies called formants. Changing the shape of the tube by arching the tongue, opening the jaws, modifying the shape of the lips or altering the position of the larynx will either lower or raise the frequency of each formant. To a certain extent we do this unconsciously, but singers learn to control these parts of their vocal tract. An example in this sense is a peculiarity of the soprano voice. A soprano must often sing tones whose fundamental is far higher in frequency than the first formant of the vowel being sung. When that is the case, the amplitude of the fundamental is not enhanced by the first formant and the sound is weak. Raising the jaw lowers the frequency of the first formant. When the first-formant frequency matches that of the fundamental, the formant enhances the amplitude of the fundamental and the sound is louder [7].

The **articulator** is composed of tongue, lips, cheeks, teeth and palate. These structures shape the sound into words and other vocal gestures.

Over time, various theories have been issued trying to explain how phonation is produced. Among these theories, the currently accepted one is

the Myoelastic Aerodynamic Theory of Phonation. According to this theory we can distinguish a myoelastic stage – the elasticity of vocal folds helps them close, and an aerodynamic phase – subglottal pressure forces vocal folds apart, Bernoulli Effect helps vocal folds close [16].

The acoustic characteristics of sound

Acoustically, a sound is characterized by pitch, intensity and timbre. The pitch of the sound is determined by the vibration frequency of the vocal folds. The longer the vocal folds, the lower this frequency, called **fundamental frequency (F0)**. This explains why male voices are lower-pitched than female and children's voices. Voice mutation in the adolescent male occurs with the increase in larynx size and the corresponding changes in F0 (1).

The mechanism of controlling voice pitch can be compared to the mechanism of changing the tone of a violin. The shorter, thinner and tauter a violin string, the higher the note it produces. The fundamental frequency of the voice depends on 4 parameters: air pressure, vocal fold elongation, muscle contraction, vocal fold tension.

Air pressure is controlled by the respiratory muscles. The other parameters are controlled by the intrinsic laryngeal muscles: cricothyroid, thyroarytenoid, lateral cricoarytenoid, posterior cricoarytenoid. In conclusion, the control of the fundamental frequency is essentially a muscular control. Achieving it is a matter of training, like the training of athletes. The term "vocal athlete" is commonly used when referring to a vocal professional. The analogies comparing a singer with an athlete are generally well perceived. The comparison with an athlete helps singers admit, like any other athlete, that they work with a muscular system that is influenced by factors such as resistance, flexibility and power, hence the need for progressive and permanent vocal training [11]. Equally important is warming up the voice before a sustained vocal effort, as well as the «cooling down» of the voice after the effort.

The **intensity** of a sound is equivalent to the sound volume, in common language. On a graphical representation of a wave, sound intensity corresponds to the amplitude of the wave it represents. The higher the amplitude, the louder the sound.

Sound intensity depends directly on: subglottal pressure and the rate of transglottal airflow. In fact, if a low subglottal pressure results in low vocal intensity, too high a pressure can, by glottal and subglottal contraction, prevent the production of the sound. Intensity can be enhanced by: increasing the tension of laryngeal muscles, increasing the closed phase of the phonatory cycle, increasing subglottal pressure and increasing the airflow in the lungs [1].

Rubin's studies [12] emphasized the importance of proper breathing during speech and singing. When a high sound intensity is produced only by increasing vocal muscle tension, with inadequate respiratory support and disrupted balance between airflow and glottal resistance, the vocal apparatus is subjected to unnecessary and harmful stress, with subsequent consequences on the quality of voice. During a *crescendo* at a constant pitch, the vocal folds must gradually relax in order to compensate for the rise in voice pitch caused by the increase in subglottal pressure. For example, an increase in subglottal pressure of 40 cm H2O accompanies an increase in frequency of approximately an octave.

Timbre corresponds to the enrichment of the laryngeal fundamental frequency by the harmonics produced by the pharyngeal-oral-labial resonator. The vocal tract acts as a resonator for the human voice. The function of vocal tract resonator can be explained by means of the source-filter theory and of the resonance tube model [16]. The totality of frequencies of a sound forms a "spectrum". The lowest tone of the spectrum is the "fundamental tone" or fundamental frequency, which is produced in the larynx, while the rest of the tones are called harmonics and are multiples of the fundamental frequency. Some of these harmonics, called **formants,** are particularly more intense. They are 2 to 4 in number and characterize the sound that is produced. Thus, any change in the shape and volume of the resonators corresponds to a change in the formants. For example, lowering the larynx by yawning will result in an elongation of the vocal tract.

Johan Sundberg's research into the vocal production of opera singers led to the concept of "singing formant", an additional vocal resonance associated with the singing voice, which is different from the speaking voice. This singing formant also helps opera singers to be heard above the orchestral accompaniment. Sundberg associates the "singing formant" with the lowering of the larynx during singing [14].

Depending on the type of voice emission, we can distinguish different mechanisms of the singing voice. First, a distinction must be made between the classical style and the non-classical one. The classical style is characterized by: low larynx position, wide-open pharynx, raised soft palate, small mouth opening / rounded mouth, moderate subglottal pressure [16]. The non-classical style is characterized by: short resonator, high larynx position, wide-opened mouth / lip retraction, increased subglottal pressure, narrowing of the pharynx. These different types of vocal emission determine the difference between musical styles and the acoustic quality of the sound.

Vocal registers

Physiologists and laryngologists use different terminologies, based on their observations of the changes that occur in the larynx. They refer to a "thick" register and a "thin" one, to accurately describe one of the changes that occur on the opposite edges of the vocal folds, which are "thick" approximately in the singer's low octave and "thin" in their high octave [11]. The register is the result of a particular adjustment of the intrinsic laryngeal muscles. The training of the intrinsic muscles can lead to significant changes in the quality of the vocal registers and can facilitate passage.

Voice classification is a frequent preoccupation of young singers. Often, they are sent to an ENT specialist in the hope that the anatomy of their vocal folds and throat will help in their voice classification. A prevailing misconception among novices is that vocal fold length determines voice type. Technical voice classification is beyond the scope of most physicians. However, the physician should be able to discriminate substantial differences in range and timbre such as between bass and tenor, or alto and soprano. Although the correlation between speaking and singing voices is not perfect, a speaker with a comfortable bass voice who reports that he is a tenor may be misclassified and singing inappropriate roles with consequent voice strain. However, classification should not be limited only to this, but should also consider voice quality and voice range [11]. Vocal classification is determined by the singing teacher. The phoniatrist assists in the process, correcting any pathological changes that may prevent a proper classification.

Notions of vocal hygiene

Vocal hygiene is the term used for the use and care of the human voice, required to keep it healthy. It facilitates recovery from voice disorders, ensures the maintenance of vocal health, plays an educational role in the proper use of the voice by identifying and correcting improper voice behaviours, prevents relapse of voice problems, increases the strength and flexibility of the singing voice [6].

Compared to non-professionals, vocal professionals are at a higher risk for vocal fold lesions, proportionately with the specific demands placed on the vocal tract. Thus, professionals often use their voice at the extremes of their vocal range, at maximum intensity and much more often than amateurs singers, and are also sociable and expansive people who use their speaking voice in excess as well. Other factors that may negatively influence the vocal tract health are: frequent journeys, frequent changes of environment and lifestyle, especially during tours [2].

One of the essential factors for vocal health is ensuring proper hydration. In order to indirectly improve the lubrication of vocal folds, increasing the amount of water consumed up to 8-10 glasses per day is highly recommended. The maximum benefit is obtained by taking sips of water continuously throughout the day, in order to "soften" the mouth and throat. By water we mean any beverages without caffeine or alcohol. The better hydrated the larynx, the more efficient the vibration of the vocal folds. Well-hydrated vocal folds may be less likely to get hurt from voice abuse [13].

Other factors that may affect hydration are: caffeinated beverages, alcohol, dry environment, sucking menthol-containing drops, medication. Milk and sweetened beverages do not count as water, because they produce a thickening of secretions. Carbonated drinks may increase reflux, therefore even caffeine-free beverages or mineral water should be used cautiously.

Smoking can be considered a form of vocal abuse. Smoking favours vocal fold irritation and causes coughing, which in turn may cause vocal fold lesions, while a long-term exposure to cigarette smoke can cause changes in vocal fold tissues, including cancer of the larynx [1].

Increased resistance to disease can be achieved through a healthy lifestyle, regular practice of physical exercise, sensible eating, an adequate

amount of rest and sleep. Attention should also be paid to reducing the risk of infections by washing hands regularly, avoiding the touching of eyes and mouth, avoiding close contact with sick persons.

Gastroesophageal reflux is an important cofactor for many voice disorders. The following measures are recommended to reduce gastro-esophageal reflux: avoiding eating 3-4 hours before bedtime, eating lighter and smaller meals at dinner, maintaining optimal body weight (but also avoiding drastic slimming diets that increase reflux), taking only prescription medication [11].

Abusive vocal behaviours should be avoided, such as: screaming/shouting, whispering, coughing/throat clearing, humming (grunting), vocalizing during exercise, speaking in noisy environments (sporting events, bars, restaurants, discos, industrial environment), singing at the extremes of vocal range, avoiding excessive speaking and singing with a cold or with acute laryngitis. Avoiding vocal abuse and misuse will ensure a healthy vocal tract and prevent the occurrence of inappropriate vocal behaviours [1].

Last, but not least, it is important to consider the effects of any drug on the voice. Many common drugs like antihistamines, antivomitives, antidiarrheal drugs, may cause the dryness of the larynx. Aspirin has anticoagulant properties and may increase the risk of bleeding into the vibratory portion of the vocal folds, causing the bruising of vocal folds. Local anaesthetics reduce kinaesthetic sensations in the vocal track and should not be used during recitals. Any drugs that affect coordination and proprioceptive sensations can lead to disasters in performance. Singers should be informed of the possible side effects of the drugs used, including homoeopathic drugs, and of their potential consequences on the voice [6].

Conclusions

In conclusion, the close collaboration between singers and researchers has obvious benefits for improving vocal emission. Singers must first understand the instrument they use and how it works, and then apply this information to the art of the singing voice. Thus, they will be

able to control and manipulate the vocal tract so as to obtain a high quality voice through a natural and healthy mode of emission.

The collaboration between science and art provides solutions for protecting and maintaining a healthy vocal tract, a goal of utmost importance for the career of a vocal professional.

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