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Şcoala Doctorală de Studii Inginereşti

ANALYTICAL STUDY OF THE DYNAMIC SYSTEM OF THE HUMAN VOCAL CORDS

Doctoral thesis – Abstract

for obtaining the scientific title of doctor at
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This doctoral thesis investigates and highlights the most important characteristics concerning the dynamics of human vocal cords. The aim of this thesis targets two research directions: an analytical direction based on the analysis of the behavior and characteristics of human vocal cord vibrations through mathematical and mechanical models, and an exploratory direction referring to the determination of fundamental voice characteristics and their influence on speech quality via an experimental study based on the voice recordings of patients with phonatory apparatus disorders and their analysis using vocal analysis software.

Thus, the objectives pursued in the elaboration of this doctoral work are:

- To explore the anatomical concepts involved in the process of human voice production, the biomechanical characteristics of the phonatory apparatus, its physiology and functioning, as well as its disorders.
- To present the current context regarding the mathematical and mechanical modeling of vocal cords, as well as the determination of the fundamental parameters of the human voice.
- To investigate and determine the analytical solutions for certain mechanical models of vocal cords.
- To identify and develop knowledge concerning the characteristics and fundamental parameters of the human voice and analyze them through vocal analysis software.
- To experimentally determine the parameters whose variations may indicate a pathology of the human phonatory apparatus.

This work follows a logical succession of chapters, combining theory with the steps required for the mechanical and mathematical modeling of vocal cords, as well as experimental vocal analysis using parameters that characterize a human voice.

Chapter 1, entitled **"Introduction"**, at first, refers to the anatomy of the structures that make up the phonatory apparatus, followed by physiological and biomechanical notions of the human phonatory system, as well as various types of human vocal cord disorders.

From an anatomical point of view, the human phonatory apparatus consists of the lungs, bones and muscles of the neck, the oral and nasal cavities, and the neck viscera (pharynx, larynx, and trachea). The focus is on the organs of the neck, as they contain the vocal cords, which represent the main subject of interest for this work.

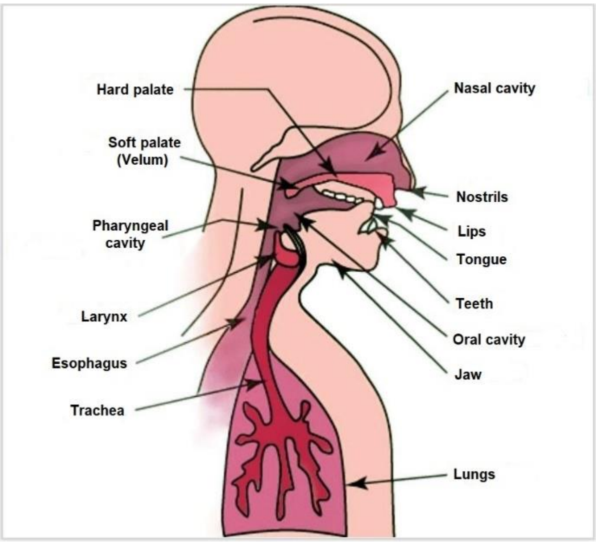

Fig. 1. Anatomy of the phonatory apparatus

The main component of interest and also the basic component of the phonatory system is the larynx. It is a channel corresponding to the last four cervical vertebrae and is connected to the other neck viscera. It is part of the respiratory tract, protects the lungs, and is also the main component of the phonatory apparatus, being considered the "voice box" [1] as it contains the vocal cords. Inside the larynx are the vocal cords, four overlapping folds, two on the left and two on the right of the glottis, made up of muscle (the vocal muscle), dense connective tissue (called lamina propria), which provides the flexibility and viscosity needed for the vibration of the cords, and squamous epithelium. The lamina propria consists of three layers: a superficial layer (Reinke's space), an intermediate layer, and a deep layer. The intermediate and deep layers together form the vocal ligament.

To understand how the human voice is produced, some aspects related to the physiology and biomechanics of the phonatory system are presented.

During phonation, the vocal cords are operated by muscles. Thus, they can be raised, lowered, brought together, separated, stretched, or relaxed by changing the position of the arytenoid cartilages to which they are posteriorly attached, and the vibrations of the cords are produced by the expired air acting on their edges and modulated by the action of the muscles.

Sound and speech production is a complex mechanism that involves two separate processes: one that produces an initial sound (phonation) and another that modifies the initial sound (articulation).

Vocal cord vibrations occur due to the action of expired air from the lungs passing through the trachea into the larynx, causing periodic opening and closing of the vocal cords. These vibrations are characterized by certain amplitudes and frequencies that depend on several factors such as the diameter of the larynx, the speed of the air, or the thickness of the cords.

The vibration of the vocal cords is a cyclic process (Fig. 2). In the first phase, air tries to exit the lungs, subglottic pressure increases, and the vocal cords narrow the air passage. When the airflow passes through this narrowing, a partial vacuum is created, bringing the vocal cord membranes together at the midline. Then, the increasing pressure forces the vocal cords away from the midline at the bottom, and the pressure wave moves upward, releasing a burst of air, and the vocal cords are completely separated. The vocal cords first return at the bottom, showing the existence of an aerodynamic effect: the space at the bottom is narrower than the space at the top, so due to the speed, the bottom closes first. The vocal cords quickly return to the median line. The two forces that bring the vocal cords together are tissue elasticity and the Bernoulli effect.

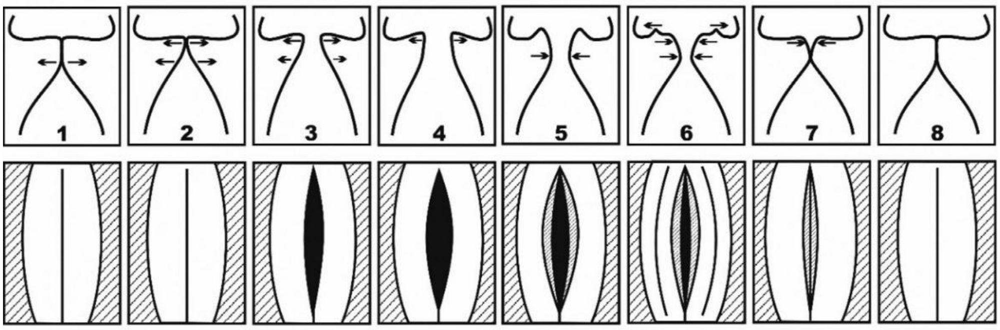

Fig. 2. Vocal fold vibration cycle [2]

Any disorders or changes at the level of the larynx, vocal cords, the human respiratory system, or any components of the phonatory apparatus can lead to various afflictions or pathologies of this structure in the human body[3].

The pathologies of interest in this doctoral thesis include chronic pseudomembranous laryngitis, also known as Reinke's edema (due to fluid accumulation in the mucosa and inflammation of its superficial layer, affecting the mass and stiffness of the vocal cord, thereby altering various fundamental frequency characteristics[4]); vocal polyps (benign tumors that appear on the vocal cord membrane, causing irregular vibrations of the cords and preventing complete glottal closure [5]); paralysis (fixation of the cords in a paramedian position, which compromises both speech and respiration); and malignant laryngeal tumors or laryngeal cancer (phonation is affected regardless of the level at which the tumor is located, and if the tumor appears at the vocal cords, it causes loss of elasticity, stiffening of the cords, and reduction of the glottic space due to the additional mass on the vocal cord).

Chapter 2, entitled **"Current state of research"**, highlights different scientific works and studies conducted to date by researchers worldwide regarding the mathematical and mechanical modeling of vocal cords and methods for vocal analysis by determining parameters that characterize the human voice, aiming to identify pathologies of the phonatory apparatus.

Primarily, mathematical and mechanical models are based on mass-spring-damper systems that analyze the behavior and characteristics of human vocal cord vibrations. These models start with a basic model (Fig. 3), featuring a single mass representing the vocal cords, where: m = mass of the vocal cords, k = stiffness of the spring, c = damping coefficient, x = displacement of the vocal cords, iar F(t) time-dependent driving force function.

Subsequent developments included systems that divided the cords into smaller sections, leading to models with two or more masses. Essential parameters for describing the human voice include those useful for identifying vocal tract pathologies.

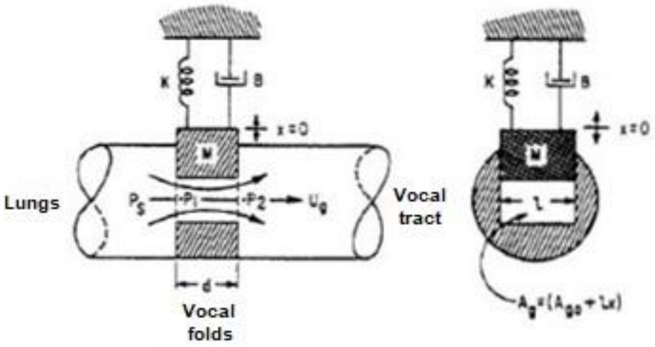

Fig. 3. One-mass model for the vocal folds [6]

The first model for the vocal cords, depicted in Fig. 3, was developed in study [6]. It is a foundational model used in numerous other research efforts in vocal cord dynamics. In this study, vocal cords were considered symmetric, and the parameters used in the mathematical model corresponded to the physiological parameters of vocal cord tension and subglottic pressure. Key findings from this study included: the airflow speed depends on subglottic pressure and vocal tract configuration, influencing the waveform shape and the fundamental frequency of the voice; to replicate normal laryngeal function, initial vocal cord vibrations were considered irregular, leading to the observation that vocal cords reach equilibrium by about the fourth vibration cycle; the displacement of the vocal cords is observable during both the opening and closing phases of the glottis; the pitch of the voice is dependent on various subglottic pressures, vocal cord tensions, and vocal tract configurations.

In other research papers, two models were used to synthesize male, female, and child voices. The first study [7] employed a single-mass mathematical model, while the second study [8] utilized a two-mass model developed by Ishizaka and Flanagan in 1972 (Fig. 4).

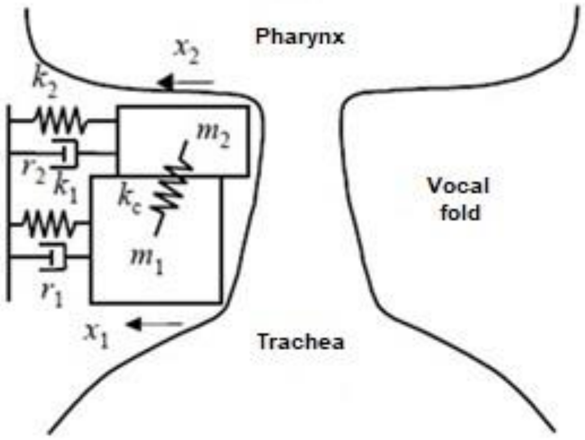

Fig. 4. Two mass model for the vocal folds [8]

The synthesized voices were perceived as realistic only when the subglottic pressure varied. This realism can be explained by the natural phenomenon where subglottic air pressure never shifts from zero to a constant value during phonation or respiration.

A key finding was that reducing the size of the larynx increases the fundamental frequency. This was demonstrated by identifying the fundamental frequency of synthesized voices for males, females, and children, with the child's voice exhibiting a significantly higher fundamental frequency.

Other research [9] reviewed existing mathematical and mechanical models of the vocal cords and proposed suggestions for improving these models based on previous findings. Suggestions included: introducing nonlinear properties of the vocal cords, implying that differential equations should contain nonlinear terms. This requires not only numerical analytical methods but also approximate solutions; analyzing the motion of vocal cords on three directions (lateral, longitudinal, and vertical) for a better interpretation of vocal cord vibrations; a more detailed analysis of the stability of vocal cord vibrations, given that the instability and irregular motion are typical for many voice disorders.

In addition to many studies on mathematical modeling of vocal cords, there is a significant body of research based on determining human voice parameters widely used for identifying various vocal tract pathologies. Among the most notable studies are those related to Jitter and Shimmer parameters. Both Jitter and Shimmer represent irregular vibrations of the vocal cords, and their levels can indicate the presence of a vocal tract disorder.

Major studies in this doctoral thesis include [10] and [11], where the authors compared Jitter and Shimmer parameters between a group of subjects with pathological voices and a group without voice pathologies. Comparisons were made against standard parameter values. The analysis involved recording patients’ voices and evaluating parameters using vocal analysis software. Conclusions highlighted significant differences in parameter values between the two groups, those with pathological voices showing instability in sustaining prolonged sounds in terms of frequency and intensity. This method is objective and non-invasive for investigating phonatory apparatus pathologies.

Another study, [12], focused on the variation of Jitter and Shimmer parameters in relation to the fundamental frequency. This analysis was conducted on a group of 60 subjects, revealing that as the fundamental frequency increases, the values of Jitter and Shimmer decrease, suggesting that improving the fundamental frequency could enhance voice quality.

Chapter 3, **"Mathematical modeling of the vocal folds"** includes several personal studies on mathematical modeling methods for analyzing the vibrations of vocal cords and investigating some mechanical models developed for vocal cords.

The modeling uses a method aimed at determining approximate analytical solutions for nonlinear differential problems, known as the Optimal Homotopy Asymptotic Method (OHAM). The efficiency and accuracy of this method are demonstrated by correlating the analytical solution obtained through OHAM with numerical integration results.

The first model investigated by means of OHAM was proposed in [13]. The model assumes complete right-left symmetry and allows for motion of tissues only in the horizontal direction. The governing nonlinear equation of motion is presented in Equation 3.1:

$$M\ddot{x} + B(1+\beta x^2)\dot{x} + Kx = P_g \tag{3.1}$$

For applying OHAM method, initial conditions are set, and the equation is transformed into a simplified equation of the form (Equation 3.2):

$$\ddot{x} + 2\mu\dot{x} + \alpha x^2\dot{x} + \omega^2 x + K_0 = 0 \tag{3.2}$$

Here, a linear and a nonlinear operator are identified, and an approximate solution is obtained from the linear differential equation (Equation 3.3) in which H(C$_i$,t) is an auxiliary function dependent on time and three convergence control parameters. These parameters are initially unknown and will be optimally identified later using various rigorous mathematical procedures. The more parameters used, the more accurate the solution, but the computations become more complex.

$$\ddot{x}_1 + 2\mu\dot{x}_1 + \omega^2 x_1 = N(x_0)H(C_i,t) \tag{3.3}$$

The final form of the OHAM analytical solution is given in Equation 3.4:

$$\begin{aligned} x_1(t) = {} & \frac{(\omega^2 - 2\mu^2)C_1 - 2\mu\sqrt{\omega^2 - \mu^2 C_2}}{9\omega^4}\left(e^{-\mu t}\cos\sqrt{\omega^2 - \mu^2 t} - e^{-3\mu t}\cos 3\sqrt{\omega^2 - \mu^2 t}\right) + \\ & + \frac{2\mu(\omega^2 - 2\mu^2)C_1 + \sqrt{\omega^2 - \mu^2}(3\omega^2 - 2\mu^2)C_2}{9\omega^4\sqrt{\omega^2 - \mu^2}}\left(e^{-\mu t}\sin\sqrt{\omega^2 - \mu^2 t} - e^{-3\mu t}\sin 3\sqrt{\omega^2 - \mu^2 t}\right) + \\ & + \frac{K_0 C_3}{\omega^2}\left[1 - e^{-\mu t}\cos\sqrt{\omega^2 - \mu^2 t} - \frac{\mu\sin\sqrt{\omega^2 - \mu^2 t}}{\sqrt{\omega^2 - \mu^2}}\right] \end{aligned} \tag{3.4}$$

To demonstrate the efficiency and accuracy of this approach, a numerical example was developed using a set of real physical parameters. The accuracy of the OHAM method is illustrated in Figures 5 and 6, comparing the analytical solution x(t) and its derivative x′(t) with numerical integration results.

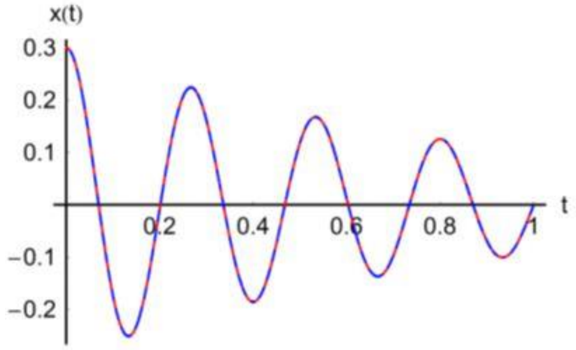

Fig. 5. Comparison between the approximate solution x(t) (blue, dotted line) and numerical integration results(red, solid line)

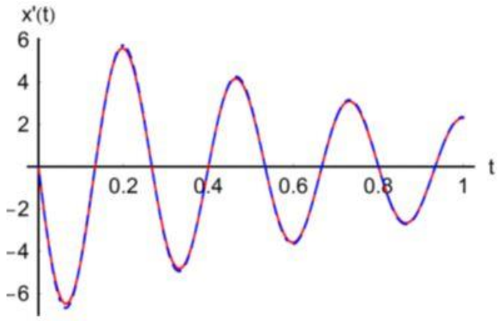

Fig. 6. Comparison between the first derivative x'(t) (blue, dotted line) and numerical integration results(red, solid line)

The overlap between the OHAM analytical solution and the numerical integration results shows excellent accuracy, validating the efficiency and applicability of this solution method.

Another model investigated using OHAM is a simple, nonlinear vocal cord model developed in [14]. The governing equation of motion is given as Equation 3.5:

$$m\ddot{x} + r\dot{x} + kx + ax\dot{x} = F \tag{3.5}$$

Following the same OHAM steps, the analytical solution was compared with numerical results. Figures 7 and 8 illustrate the graphical comparison, showing a precise match, further demonstrating the effectiveness of this method for solving nonlinear differential equations.

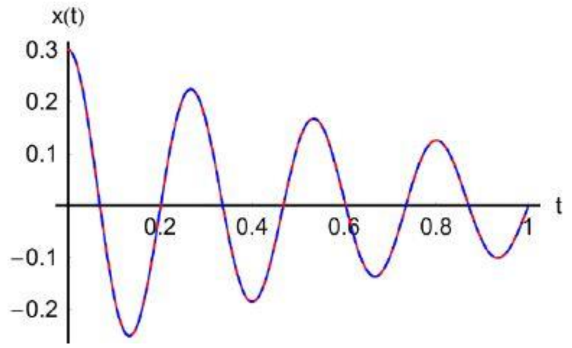

Fig. 7. Comparison between the approximate solution x(t) (blue, dotted line) and numerical integration results(red, solid line)

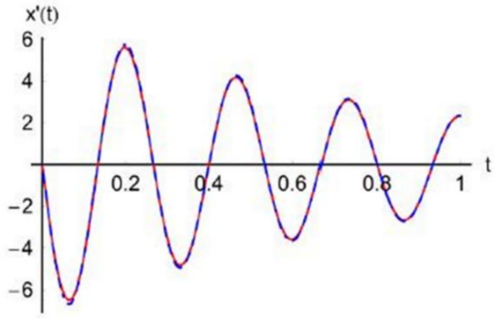

Fig. 8. Comparison between the first derivative x'(t) (blue, dotted line) and numerical integration results(red, solid line)

A third model investigated by means of OHAM is the mucosal wave model, which involves small amplitude oscillations of the vocal cords, representing the oscillatory motion as a surface wave propagating through the mucosa along the airflow direction. This model, developed by Titze and emphasised in [8], is governed by Equation 3.6:

$$m\ddot{x} + r\dot{x} + kx = dl_g \frac{2\tau P_S \dot{x}}{a + x + \tau\dot{x}} \tag{3.6}$$

As shown in Figures 9 and 10 below, the accuracy and efficiency of OHAM are again validated by the excellent match between the analytical solution and numerical integration.

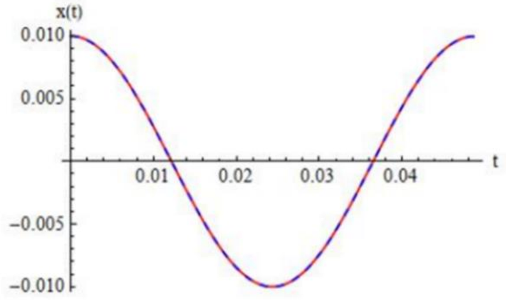

Fig. 9. Comparison between the approximate solution x(t) (blue, dotted line) and numerical integration results(red, solid line)

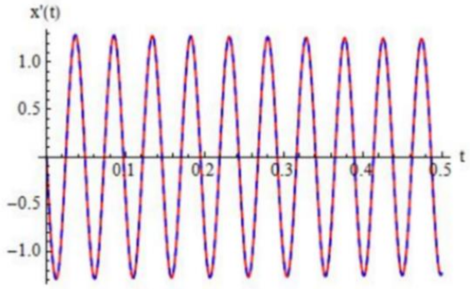

Fig. 10. Comparison between the first derivative x'(t) (blue, dotted line) and numerical integration results(red, solid line)

Chapter 4, entitled **"Vocal analysis and recording of voice"** primarily presents a personal study that reviews some of the most important studies on using Jitter and Shimmer parameters to identify laryngeal disorders.

In all the selected studies, emphasis was placed on several crucial characteristics of the human voice: fundamental frequency, Jitter, and Shimmer. These were determined from voice recordings of subjects using various vocal analysis software.

In most of these studies, a comparison was made between groups of people with healthy voices and groups with associated voice pathologies, such as stuttering [11], [15], laryngeal lesions [10], vocal cord polyps [16], and Reinke's edema [17]. Other studies involved voice recordings from a single group of subjects, for which voice parameters were determined [12], [18], [19]. The results highlighted both clear differences between pathological and healthy voices and the efficiency of vocal analysis programs, which are considered simple and non-invasive methods for identifying possible disorders of the human phonatory apparatus.

Further, this chapter describes the vocal analysis software used in the experimental section (Praat), the characteristics of vowels, the fundamental parameters for describing the human voice (intensity, vocal timbre, pitch, phonation time, Jitter, Shimmer, HNR, voice breaks), and the processes of articulating and phonating human sounds. Through the acoustic analysis of human vocal sounds, it is possible to identify and evaluate voice disorders. This type of analysis is performed using vocal analysis software that allows extracting the most relevant acoustic parameters.

Praat [20] is one of the most widely used vocal analysis software globally, capable of processing a wide range of voices and identifying and extracting the fundamental characteristics of a human voice, such as:

- Pitch (fundamental frequency F_0): The number of vibration cycles produced by the vocal cords per second. According to the literature, women have an average pitch of about 260 Hz, ranging between 200-500 Hz, men have an average pitch of 130 Hz, ranging between 100-300 Hz, and children have a pitch above 250 Hz [21].
- Intensity (volume of the voice): Measured in decibels, it characterizes the amplitude of the sound wave emitted by the human voice.
- Vocal timbre: The combination of the fundamental sound with its harmonics [21]. The harmonics refer to the resonant frequencies of the vocal tract, called formants (a deep timbre is characterized by lower formants, high formants give clarity to the voice, and mid-formants characterize a nasal timbre).
- Jitter: The cycle-to-cycle variation in fundamental frequency during successive vibration periods of the vocal cords [21]. A higher Jitter percentage indicates the presence of phonatory disorders, with perturbations in sound frequency varying between 0.5% and 1% according to numerous studies.

- Shimmer: perturbations in amplitude of consecutive periods in the signal. Increased Shimmer values indicate changes in vocal cord mass or lesions, leading to an inability to maintain a constant vibration during phonation. Like Jitter, the Shimmer threshold is set at 3.81% in the literature.
- Harmonics-to-noise ratio (HNR): The ratio between harmonic and non-periodic components in a sound. Higher HNR values increase voice quality, whereas values below 20 dB [20] indicate the presence of a phonatory pathology.

Besides the essential characteristics mentioned above, understanding the primary processes involved in speech production is crucial for voice evaluation:

- *Articulation of sounds*: The process in which the organs of the phonatory apparatus interact to produce and shape a voice. It involves the uvula, hard palate, soft palate, teeth, alveolar ridges, and lips.
- *Phonation process*: It involves the other organs of the phonatory apparatus and refers to the process where air expelled from the lungs passes through the larynx and is modulated by the vocal cords.

These two processes are interdependent in sound production. Human vocal sounds can be classified as tones or noises, depending on the periodic or non-periodic nature of the vibration produced by the vocal cords. Periodic vibrations primarily represent vowels, while non-periodic vibrations represent consonants.

The sounds of interest in this doctoral thesis are vowels, which are classified based on three criteria: the degree of oral cavity opening (open, semi-open, closed); place of articulation (anterior, central, posterior) and roundness of the lips (rounded, unrounded).

Considering this classification, a graphical representation of the vocalic system, Fig. 11, was created according to the International Phonetic Alphabet [22], showing the seven Romanian vowels based on the frequencies of their first two formants (the first formant is inversely proportional to the vowel's height, while the second formant is related to the vowel's place of articulation, i.e., its anteriority or posteriority).

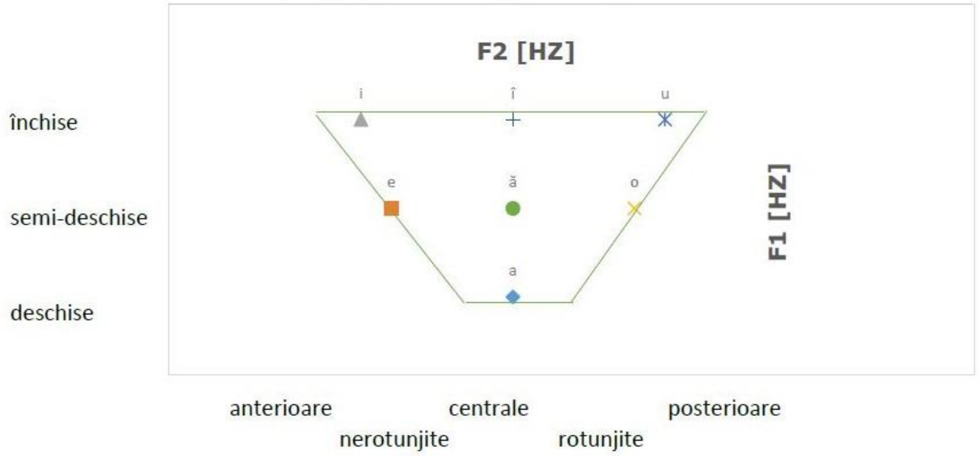

Fig. 11. Schematic representation of vowels

Chapter 5, entitled **"Experimental determinations for identifying parameters used in vocal analysis"** focuses on the experimental determination of parameters used in vocal analysis for identifying pathologies of the phonatory apparatus. It describes the voice recording protocol, data extraction and processing, and the creation of various graphs and tables to highlight the efficiency of using a non-invasive technical method for detecting pathologies, utilizing vocal analysis software.

A study was conducted based on data collected from the Emergency Clinical Municipal Hospital Timișoara, approved by the hospital administration and with favorable approvals from the heads of the Otolaryngology and Radiotherapy departments.

Data collection and voice recording of patients took place only after obtaining a signed informed consent from each patient, which included the patient's acknowledgment of the study's purpose, procedure, duration, and potential risks, and assured the confidentiality and proper use of personal data.

The collected and used data included patient age, diagnosis, gender (female/male), and smoking habits. Only patients diagnosed with severe forms of chronic laryngitis, malignant tumors of the larynx and vocal cords, vocal cord polyps, and vocal cord paralysis were selected. The criteria for participation was that patients had to be in preoperative stage and admitted to the Radiotherapy or Otolaryngology departments of the hospital.

An vocal audio recording was performed on a group of patients comprising 14 men and 8 women, all smokers, aged between 29 and 75 years, diagnosed with known pathologies of the human phonatory apparatus. All recordings were made directly in Praat vocal analysis software using a unidirectional microphone. Patients were seated and instructed to position the microphone near their mouth, approximately 10 cm (or four fingers' distance) away, as shown in Figure 12, and to phonate the vowels [a], [e], [i], [o], and [u] sequentially at a comfortable frequency and intensity, sustaining each vowel for as long as possible.

Fig. 12. Recording protocol

For vocal analysis in this doctoral thesis, the following voice characteristics were chosen: fundamental frequency F_0; the first two formants (F_1, F_2); Jitter (measured as percentage); Shimmer (measured as percentage); and the Harmonics-to-Noise Ratio (HNR). To identify possible pathologies in the human phonatory apparatus, the results were compared with normative values identified in previous research in this field.

Schematic representations (vowel maps) were created for each patient's vowels and compared with vowel schematics for healthy voices (using formant values identified in [23]). Significant differences in vowel height and place of articulation were identified across all types of pathologies, with the most notable differences observed when two laryngeal pathologies were associated, as shown in Figure 14 (in this case, vocal cord polyp and malignant vocal cord tumor).

Table 1. F_1 and F_2 [Hz] in the association of two pathologies: vocal cord polyp and vocal cord tumor

Vocală	**F_1 [Hz]**	**F_2 [Hz]**	**Deviație standard**	
			F_1 [Hz]	**F_2 [Hz]**
a	779.1118	2271.9989	70.8882	-661.9989
e	337.0796	2130.1855	52.9204	169.8145
i	258.9281	2311.4511	-18.9281	88.5489
o	396.2124	1175.4113	-36.2124	-535.4113
u	432.6391	1641.2589	-182.6391	-1046.259

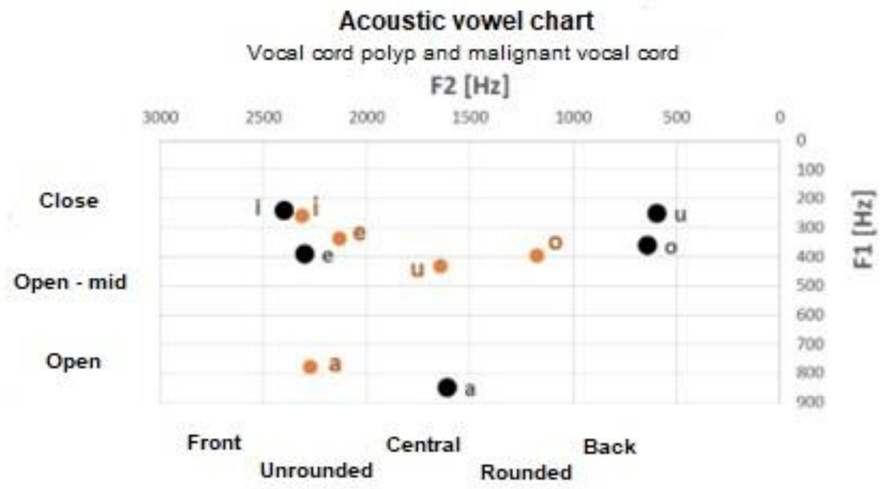

Fig. 13. Acoustic map of vowels in the association of two pathologies: vocal cord polyp and malignant vocal cord tumor (● – healthy voice, ● – pathological voice)

Changes in vowel articulation may result from the additional mass that both polyps and tumors add to the vocal cords, thus affecting the air passage through the glottis and causing instability in the movements of the cords and other structures involved in phonation.

In this particular case, the most significant deviations were observed for the vowels [a], [o], and [u]. For example, vowel [a] changed from a central vowel to an anterior vowel (the lingual muscle properties were affected, no longer maintaining an intermediate position); vowel [o] remained rounded with the lingual muscle in a posterior position but shifted to a central location; for [u], significant increases in the frequencies of both formants resulted in a complete shift in its location, making it a central, unrounded, and semi-open vowel.

Mapping vowels according to different pathologies provides a useful method for successful vocal analysis and indicates the potential presence of a pathology.

Additionally, there are several other parameters that can lead to the rapid and easy identification of phonatory apparatus disorders. In this doctoral thesis, these characteristics were determined by extracting parameters directly from the Praat analysis software and processing them to determine average values based on existing pathologies and gender.

The main objective was to identify vocal characteristics for patients diagnosed with malignant laryngeal tumors, who constituted the majority of the study group.

The first characteristic analyzed was the fundamental frequency. To compare the pathological voice values, normative average values of the fundamental frequency from [24] were used. Results for both female and male subjects indicated that this type of laryngeal pathology causes various structural and mechanical changes in the vocal cord tissue, such as: altering vocal cord mass (tumors add extra mass to the vocal cords), resulting in a lower fundamental frequency; changes in vocal cord tension if the tumors affect the muscles regulating this tension, also leading to a decrease in frequency; modifying the anatomical shape of the cords due to tumor size and inflammation (changing cord thickness and length), leading to fundamental frequency changes.

For all patients diagnosed with malignant laryngeal tumors, Jitter values exceeded the normative interval (0.5-1%). This can be observed in Figure 14, which illustrates the frequency perturbations for patients with laryngeal tumors. These increased values may result from the loss of vocal cord elasticity, sometimes leading to their stiffening.

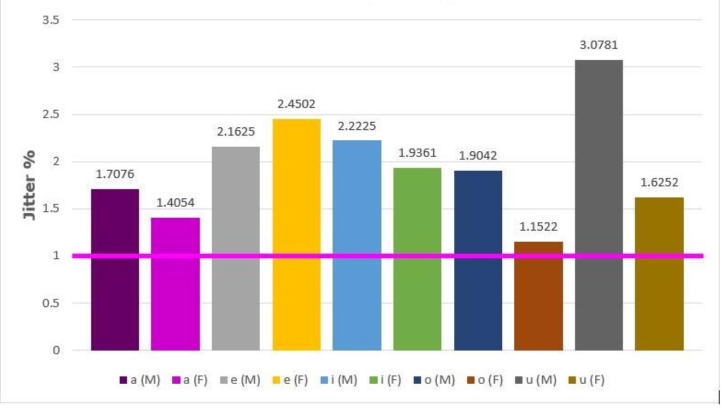

Fig. 14. Jitter [%] by gender in malignant laryngeal tumor (M – male, F – female, __ normative upper limit for Jitter in healthy voices)

Similarly, Shimmer values for both female and male patients showed clear differences from the threshold value of 3%. The most significant differences were observed in male patients, as illustrated in Figure 15.

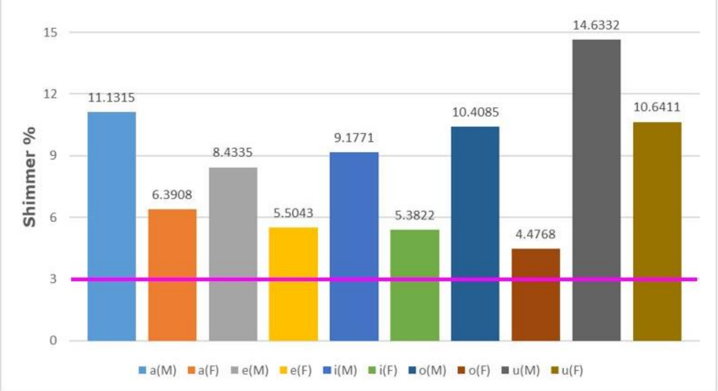

Fig. 15. Shimmer [%] by gender in malignant laryngeal tumor (__ normative upper limit for Shimmer in healthy voices)

These amplitude perturbations in the signal (Shimmer) are influenced by existing lesions on the vocal cords and reduced glottal resistance, often correlating with a hoarse voice and additional noise [25].

Another essential parameter in human voice analysis is HNR. This ratio, representing the acoustic energy of harmonics to non-harmonics, is influenced by other characteristics (Jitter, Shimmer, F_0). In contrast to the previously presented parameters, a higher HNR indicates greater harmonicity (HNR > 20 dB). During phonation, the glottal space naturally narrows less in men than in women, meaning that for men, the level of harmonics is lower, and noise becomes more pronounced. This was observed in this study, where female patients with laryngeal cancer had higher HNR values than male patients, although still below the 20 dB threshold for healthy voices.

Determining these essential characteristics of the human voice through extraction from vocal analysis software can serve as a non-invasive technique of significant utility in identifying pathologies that may affect human voice quality.

Chapter 6, entitled **"General Conclusions and Personal Contributions"** presents the general conclusions of the doctoral thesis, the author's personal contributions, and potential future research directions in the field of human vocal cord vibrations.

This research primarily emphasized some of the most critical aspects necessary to understand how the human voice is produced. This understanding starts with the knowledge of the anatomical structures involved in the speech process and their interactions, from both biomechanical and physiological perspectives, and extends to the description of the disorders of interest (malignant tumors, paralysis, Reinke’s edema, vocal polyps).

A major part of this work was dedicated to a personal study focusing on human voice analysis and mathematical modeling of vocal cords, aiming to correlate and compare the experimental data with findings from previous scientific research in the field of vocal fold dynamics.

In this doctoral thesis, a simple and non-invasive method was utilized to identify possible pathologies of the phonatory apparatus affecting the speech process. Experimental determinations were made, followed by data processing to create essential graphical representations that demonstrated the efficiency of this method in identifying voice disorders.

The key personal contributions of this doctoral thesis are as follows: demonstrating the efficiency and utility of mathematical and mechanical modeling by investigating these models using the OHAM method; highlighting the importance of experimental determination of the primary characteristics of the human voice for identifying pathologies and disorders that can arise in the vocal tract; comparing these experimental findings with normative levels to better understand deviations caused by various pathologies.

Lastly, the following potential research directions have been identified: development and investigation of more mathematical models (further exploration of new mathematical models for vocal cords to enhance the understanding of their dynamics and behavior under different conditions); continuous development of experimental methods (refining experimental methods for more accurate identification of vocal pathologies); comparative analysis of pre- and postoperative results (observing and comparing the behavior of vocal cords before and after surgical interventions); use of stroboscopy (applying stroboscopic techniques to observe vocal cord oscillations and the entire phonation process for a more comprehensive analysis); 3D modeling and finite element analysis of the vocal folds (especially in cases involving additional masses such as tumors or polyps).

This thesis aims to contribute significantly to the field of vocal cord dynamics by offering both theoretical insights and practical applications for identifying and understanding phonatory disorders.

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