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Preliminary study of Data Mining analysis of High-speed Kymography and voice data.

Estudio preliminar de Análisis de minería de datos de quimografías de alta velocidad y señales de voz

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Resumen

El uso de la tecnología en el área de la salud contribuye al diagnóstico y tratamiento de casi cualquier patología laríngea, incluida la parálisis unilateral de las cuerdas vocales. La videolaringoscopia de alta velocidad es una técnica que captura el verdadero comportamiento vibratorio intraciclo de las cuerdas vocales. Las cámaras de alta velocidad pueden grabar cuadros de hasta 4000 cuadros por segundo y generar una gran cantidad de datos laríngeos. Por otro lado, la minería de datos es un proceso de exploración de datos capaz de identificar patrones entre información y agruparlos de acuerdo con algunos criterios dados. **Objetivo:** Identificar, a través de un sistema computarizado de minería de datos, los criterios para el análisis de imágenes laríngeas y señales acústicas de voces con y sin parálisis unilateral de cuerdas vocales. **Metodologia:** Las imágenes laríngeas transformadas en kimografía de alta velocidad y señales de voz acústicas de sujetos con y sin parálisis unilateral de cuerdas vocales capturadas por videolaringoscopia de alta velocidad fueron analizadas por un sistema computarizado de minería de datos, el DAMICORE SYSTEM. **Resultados**: para el sistema de minería de datos de kimografía de alta velocidad de individuos sanos se encontró el sexo como un criterio de recolección, mientras que las imágenes de los sujetos con parálisis vocal unilateral se recolectaron mediante un contraste de colores, ya sea por la mucosa laríngea o por la incidencia de luz en las imágenes . Con respecto a las señales de voz acústicas, la técnica consideró la presencia de ruido externo como un criterio para reunir ambos grupos. **Conclusión:** Llegamos a la conclusión de que DAMICORE era una herramienta eficaz para la extracción de datos laríngeos y vocales, y era más sensible a las imágenes grupales que a las señales acústicas de voz..

Abstract

The use of technology in the area of health contributes to the diagnosis and treatment of almost any laryngeal pathology, including unilateral vocal fold paralysis. High-speed videolaryngoscopy is technique that capture the true intracycle vibratory behavior of the vocal folds. High speed cameras can record frames rates up to 4000 frames per second and generate a big amount of laryngeal data. In the other hand Data mining is a process of data exploration capable of identifying patterns among information and grouping them according to some given criteria. **Objective***: To identify, through a computerized data mining system, the criteria for the analysis of laryngeal images and acoustic signals of voices with and without unilateral paralysis of vocal folds.* **Methodology:** *Laryngeal images transformed into high-speed kymography and acoustic voice signals of subjects with and without unilateral paralysis of vocal folds captured by high-speed videolaryngoscopy were analyzed by a computerized data mining system, the DAMICORE SYSTEM.* **Results***: for High-speed kymography of healthy individuals data mining system found sex as a gathering criteria , while images of the subjects with unilateral vocal fold paralysis were gathered by a contrast of colors, either by the laryngeal mucosa or by light incidence in the images. Concerning acoustic voice signals, the technique considered the presence of external noise as a criterion for gathering both groups.* **Conclusion***: We concluded that DAMICORE was an effective tool for laryngeal and vocal data mining, and it was more sensitive to group images than voice acoustic signals.*

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Introduction

Voice and High-Speed Imaging

Voice production occurs through the interaction of different organs and structures of the human body. The larynx is the structure responsible for phonation and corresponds to the organ where the vocal folds are located. The glottic area is formed by the space surrounded by the edges of the vocal folds, during which the vibrations form the glottal area waveform (Hirano & Bless, 1997). The voice is the sound reproduced by the vibration of the vocal folds, which undergoes modifications along other structures that compose the vocal tract (Behlau, 2001).

An important structure for the production of voice is the nervous system. The main pair of nerves responsible for laryngeal innervation is the *Vagus* Nerve. It is the tenth pair of cranial nerves originating from the nucleus of the base (in the brain); its branches insert into the muscles of the larynx.

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To keep their functions, the vocal folds depend on the integrity of the *Vagus* Nerve from its origin in the brainstem until its ramifications and insertions in the larynx. Lesions in any point inside this trajectory can lead to paresis or vocal fold paralysis (Steffenl, Moschettill, Steffen, & Hanayama, 2004).

Although vocal fold paralysis is still an unknown incidence, both in Brazil and in the rest of the world, its occurrence has become common in medical and speech-pathologist clinics. (Schindler, et al, 2008). The causes of vocal fold paralysis may have a central or peripheral origin, and they may occur abruptly or progressively, unilaterally or bilaterally. Unilateral vocal fold paralysis is the most common, with left vocal fold paralysis being more frequent due to the longer size of the left *Vagus* Nerve, making it more susceptible to injury. (Colton, Casper, 2006; Behlau, 2009; García et al., 2009). The patient with unilateral vocal fold paralysis may present some or all the symptoms of vocal disorders. (Schindler, et al, 2008; Gama et al., 2011; Bustos- Crespo et al., 2016). Therefore, it is essential to perform an accurate and reliable diagnosis, as well as to monitor techniques of the therapeutic process.

The use of high-speed videolaryngoscopy contributes increasingly to promote greater objectivity in the characterization of laryngeal physiology and physiopathology, as well as in the diagnosis and monitoring of laryngeal diseases. In high-speed videolaryngoscopy, it is also possible to extract the acoustic signal from the voice, which is captured simultaneously with the recordings of the laryngeal images. These acoustic voice signals can contribute to the characterization of vocal physiology.

High-speed kymography has enabled the analysis of vocal fold vibration, adding an important piece of information to high-speed videolaryngoscopy data. By visualizing the movement of the vocal folds in a perpendicular line drawn generally in the medial portion of the glottic area, which is the maximum range of motion, it is possible to observe irregularities in the vibratory behavior of the vocal folds. (Larsson, Hertegård, Lindestad, & Hammarberg, 2000). In addition, the high-speed kymography allows a quantification of the vocal fold vibration, as well as to observe the presence of asymmetry in the vibratory pattern (Svec & Schutte, 2012).

Several studies in recent years have used the technique of high-speed kymography to analyze laryngeal images. (Pimienta et al. 2013) published a study combining acoustic parameters and high-speed kymography to identify the effects of vocal exercises on the larynx. They identified vocal fold dynamic changes after performing sound vibration and basal sound. In the high-speed kymography, there was a reduction in the times of the closed and closing phases, and an increase in the open phase in the female vocal folds after sound vibration. After the basal sound exercise, they identified reduction in the closing phase time in the male vocal folds. (Baraviera et al. (2014) compared the parameters of videolaryngoscopy and high-speed kymography of 18 normal subjects. They verified the need to establish different standards of normality for each evaluation technique from the results obtained, which showed significant differences in the duration of the vibration cycle phase times and the opening coefficient, although the fundamental frequency was similar. (Tsutsumi et al., 2016) published a study characterizing laryngeal parameters using glottal area waveforms and high-speed kymography in healthy subjects. In this study, parameters indicative of normality using these two techniques of voice analysis were found. For high-speed kymography, 0.62 was found as a parameter of normality for the opening coefficient in women and 1.02 for the speed coefficient. For men, 0.57 of opening coefficient and 1.12 of speed coefficient.

Data Mining

Data mining is an efficient technique for extracting information from a large volume of data, discovering correlations between them and predicting future trends, helping to make quick decisions. (GALVÃO, 2009). In the process of data mining, patterns are generated that need to be interpreted and analyzed, creating a so-called "new knowledge." In this stage of data mining, artifacts are generated from the results obtained, which can be graphics, tables or trees (Moro, 2015).

For the process of data mining, it is necessary to use a tool that combines computational techniques to extract and analyze such data and to characterize them according to their standards. A computational tool was created for data mining in scientific applications, and it has attracted the attention of researchers from several areas. The DAMICORE (DAta MIning of COde REpositories) (Sanches, Cardoso, & Delbem, 2011) is a computational tool based on the hierarchical data grouping method used for complex data mining (Andrade et al. 2016)

DAMICORE works with a combination of algorithms described below: Normalized Compression Distance (NCD), Information Theory; (Cilibrasi, Vitany, 2005) NeighborJoining (NJ), phylogenetic (Felsenstein, 2004) and FastNewman (FN), Complex networks. (McLaren et al., 2008)To use DAMICORE for data mining, it is necessary to insert files of the same type into a repository, and each image, voice or subject of the sample must be put in a different file. The combination of the application of different techniques makes it possible to mine the data to be analyzed. The NCD technique calculates the distance, gathering and compression of information. This metric allows finding the correlation between the analyzed data. (Moro et al., 2014). Then, the NJ technique builds a phylogenetic network. It is one of the simplest and most efficient algorithms to create phylogeny. According to (Sanchez et al. 2011), NJ is best suited to deal with a wide variety of data types.

Finally, the FN technique is applied because once a phylogeny is found, it is necessary to verify the existence of subtypes, and for this specific purpose, Complex Networks are used to identify and create the clusters (Moro, 2015).

The present study is not intended to be used as a tool for therapeutic purpose however, it proposes the use of it as an aid to the classification of laryngeal images of high-speed kymography with the possibility of future application. The images of high-speed kymography present a lot of information from both the quantitative and qualitative point of view. In addition, to make the extraction of quantitative parameters, such as phase times of the vocal fold vibratory cycle, the high-speed kymographic images provide qualitative parameters regarding the color differences representative of the phases of the vibratory cycles, physical characteristics of the vocal folds as well as coloration of the laryngeal mucosa.

Considering the effectiveness of the use of data mining to analyze and categorize a large amount of information, the present study proposes to use DAMICORE for the mining of voice data to analyze high-speed kymographic images and vocal acoustic signals to improve and automate the categorization of laryngeal images. It is hoped that such a procedure can be extended to massive amounts of images, accelerating the analysis of health information based on predetermined criteria automatically.

Methodology

Database

This study was financed by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-Brasil (CAPES) -Finance Code 001.

To compose the sample of this study, high-speed videolaryngoscopy images were selected from the database of the Medical Engineering Research Group of the National Council for Scientific and Technological Development (GPEM / CNPq). We selected the recordings of forty-five healthy subjects and thirty-five patients with unilateral vocal fold paralysis. The data were composed of laryngeal images and voice signals extracted from high speed videolaryngoscopy. The sample characterization is shown in Table 1:

Table 1. Characterization of the subjects whose data were used in the samples of the present research.

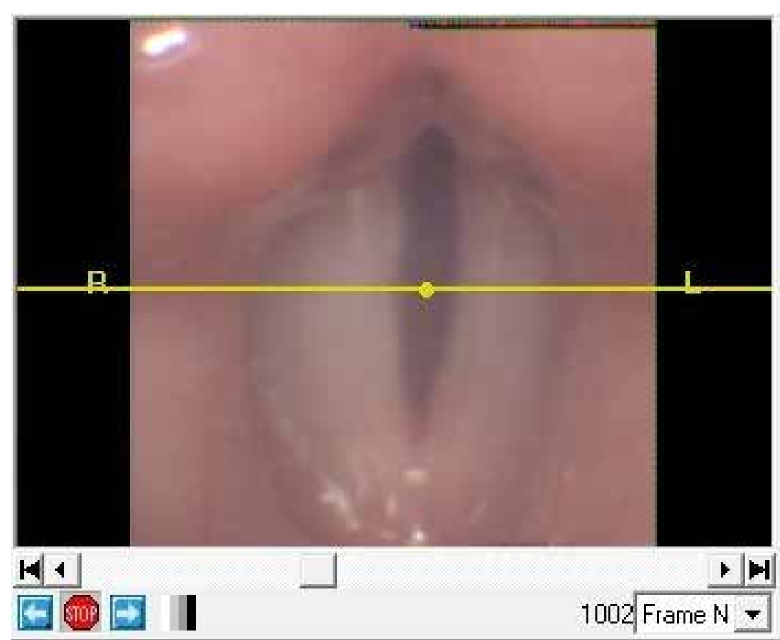
	N	
	M	F
Normal	19 (X= 31,42 / SD=9,33)	26 (X= 27,34 / SD =4,96)
Paralysis	11 (X=57,64 / SD =21,35)	24 (X=57,25 / SD =13,87)
N= sample M= male F= female X= age average SD= standard deviation of age average		

Source: owm elaboration of author

High-speed videolaryngoscopy examinations were performed by an experienced laryngologist at the Outpatient Clinic of the Otorhinolaryngology Division of Clinical Hospital-Sao Paulo University Medical School (HC-FMUSP). The high-speed image recording system used was Richard Wolf (Knittingen, Germany) with a high-performance light source (AUTO LP **5132),** a rigid laryngoscope (**90°** angle) and a head chamber (HRES ENDOCAM **5562**). The exams were sampled at **4000** frames per second and converted to .AVI file extension for image processing.

The high-speed kymographs were automatically generated from the laryngeal images. For the creation of the high-speed kymography, a midpoint was selected in the laryngeal image (Figure 1). from which the juxtapositions of the frames occurred over a specific period to obtain the kymographic image (Figure 2).

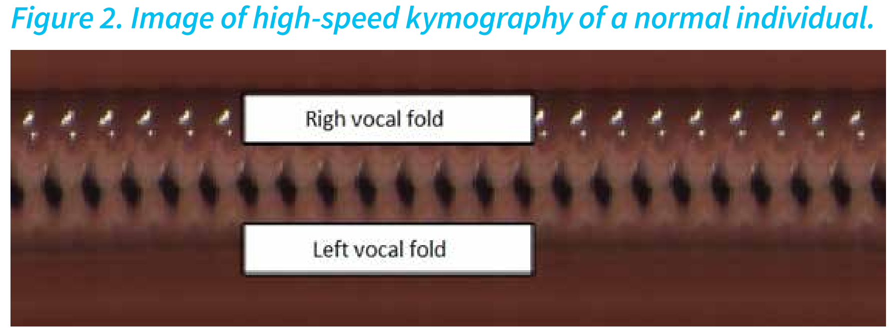
Figure 1. Midpoint selection in the laryngeal image (superior view of glottic area).



Source: owm elaboration of author

To obtain the high-speed kymography, the image is rotated 90° to the right, with the right vocal fold being represented in the upper part of the image, and the left vocal fold in the lower part.

Figure 2. Image of high-speed kymography of a normal individual.



Source: owm elaboration of author

The software used for the capture of laryngeal images and acoustic signals (HRES) was also used for processing voice recordings. The acquisition of the voice samples to be analyzed was possible through the edition of acoustic signals in a specific acoustic analysis software (Audacity). In this pre-processing, one second of each vocal acoustic signal of the samples selected for this study was edited. The high-speed kymographic images were saved in three different extensions: .bmp, .jpg and .png. The acoustic signals of the voices were saved in a .wav extension. The data were divided in two archives: i) normal and ii) paralysis. Therefore, the data were organized (images and acoustic signals) to be inserted into the computational data mining tool DAMICORE.

Data Mining

The DAMICORE system was used for this research. DAMICORE is a tool based on the hierarchical data collection method. The analyses were performed with each image file and acoustic signal being placed separately. Three compressors were tested: gzip, bzip2 and zlib to verify which would present better results in the analysis of laryngeal images. It is an image processing procedure that precedes the analysis step. For this study, the result obtained with the best compression for each file extension was considered.

As results of the data mining were generated, "trees" gathered the items of the samples according to different criteria. The "trees" are composed of "branches" and "leaves," representing sub-groupings (Figure 3. "Tree" generated by DAMICORE with description of branches and leaves).

Figure 3. "Tree" generated by DAMICORE with description of branches and leaves

sourcer: ***Moro, Rodrigues, Andrade, Delbem, & Isotani, 2014.***

From the results, interpretations were made regarding the possible criteria considered by the tool to justify the observed groupings.

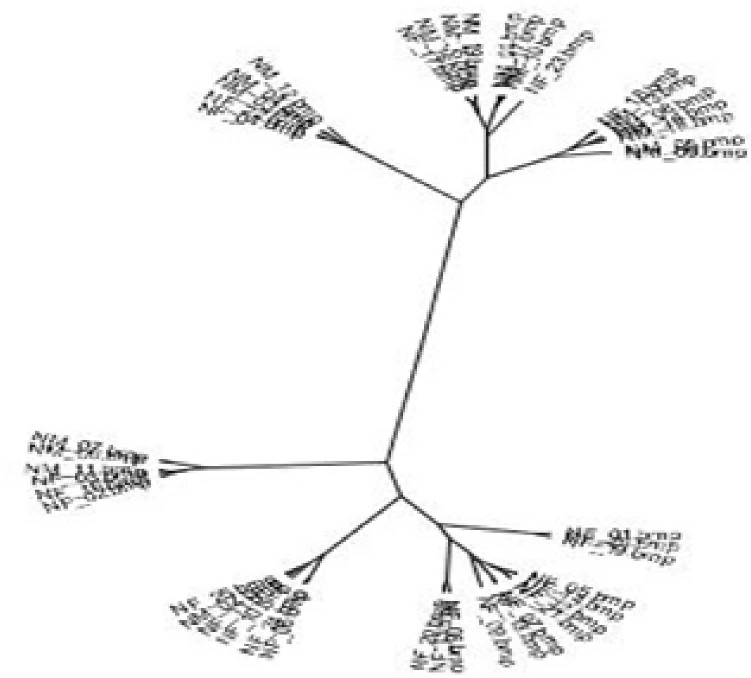
Results and discussion

High-speed kymography Images

High-speed kymography of normal individuals

In the interpretation of the "tree" generated from the high-speed kymography of subjects with normal voice, it was possible to observe, in the .bmp (compressor zlib) extension (Figure 4. "Tree" generated from high-speed kymography data from normal (healthy) individuals, a clear grouping process considering the gender criterion (male and female). The possible justification refers to the difference in color contrasts (light and dark) in the images. Considering that the tool was sensitive in identifying the repeated glottal spaces, which are identified by a dark color in the images, and there is a confirmed difference described in the literature between the configuration of male and female laryngeal images (LOHSCHELLER et al., QIU et al, 2003).

Figure 4. "Tree" generated from high-speed kymography data from normal (healthy) individuals. (NM: normal, male; NF: normal, female; .bmp: extent to which the image was stored).

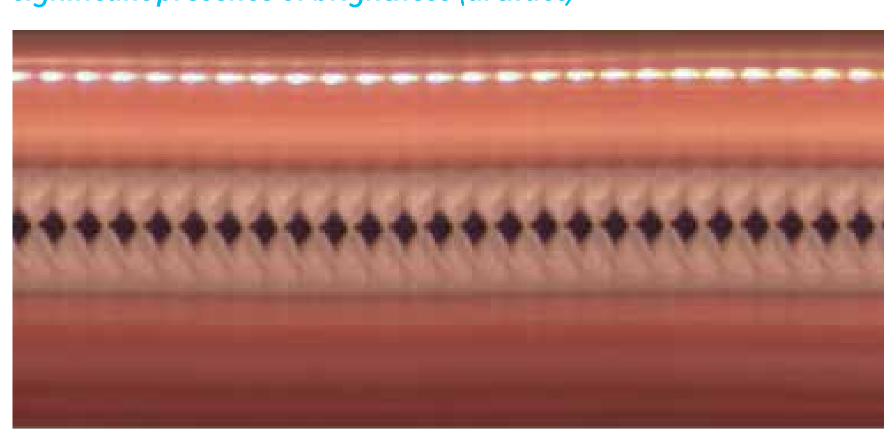


Source: owm elaboration of author

It was possible to observe that the .bmp extension presented the best compression in comparison to the other compressors used in this study. In addition, the .bmp is the original format file generated by the system software (HRES), therefore it preserves all its characteristics.

In the analysis of normal laryngeal images with .jpg (compressor gzip), there was the possibility of grouping by gender, but without the consistency observed in the .bmp extension. A similar result occurred with the data in the .png extension (gzip compressor), where it is possible to observe a tendency of grouping when there is a difference in light incidence, the presence or not of the glottic area, and the reflection of the light applied during the collection of the image (Figure 5 and Figure 6. High-speed kymography of normal individuals with significant presence of brightness).

Figure 5. High-speed kymography of normal individuals with significant presence of brightness (artifact)



Source: owm elaboration of author

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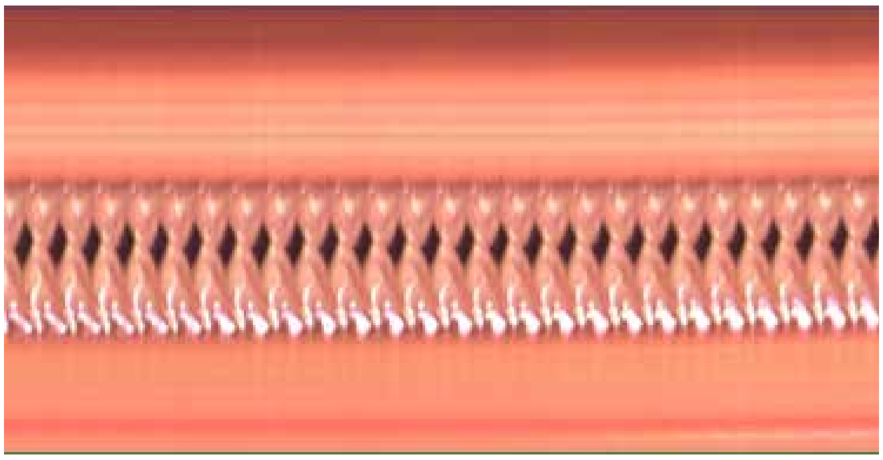
Figure 6. High-speed kymography of normal individuals with significant presence of brightness (artifact)

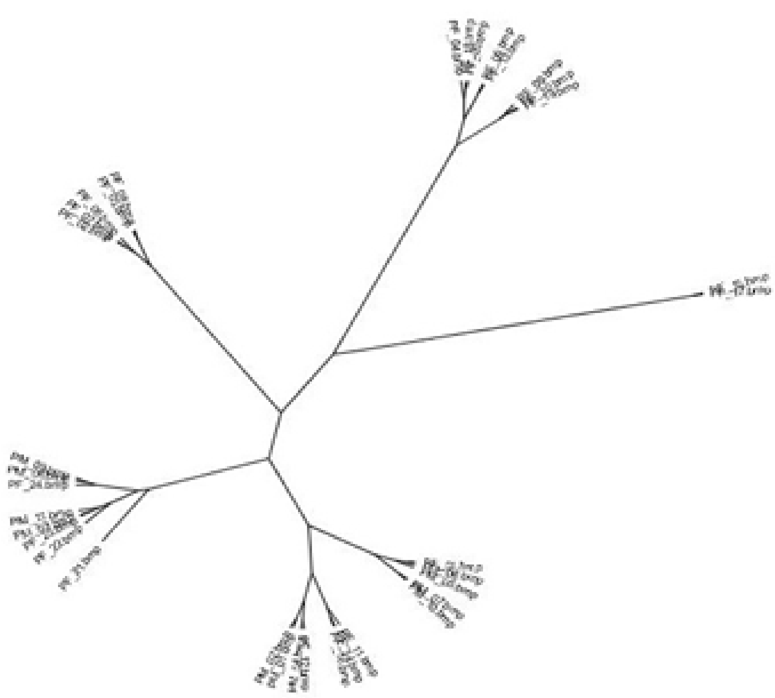


Source: owm elaboration of author

High-speed kymography of unilateral vocal fold paralysis individuals

Concerning the analysis of the "tree" generated from unilateral vocal fold paralysis image data, it was observed in the .bmp extension (gzip compressor) a tendency of grouping due to the identification or lack of in areas with color contrasts (light and dark) interspersed, representing the phases of the glottic cycle (Figure 7).

Figure 7. "Tree" generated from high-speed kymographic data of subjects with unilateral vocal fold paralysis. (PM: paralysis, male, PF: paralysis, female, .bmp: extent in which the image was stored).



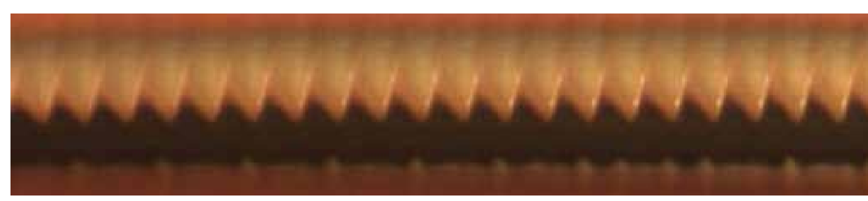
Source: owm elaboration of author

However, to perform data grouping of individuals with unilateral vocal fold paralysis, the DAMICORE tool does not seem to consider the gender criterion as observed in the analysis of healthy individuals. Also, no data grouping was observed according to the side of the paralyzed vocal fold. One data to be studied concerns the results of an analysis that subjectively evaluates the position of the paralyzed vocal fold in relation to the glottic area.

The vocal folds may assume different anatomical positions due to laryngeal paralysis. However, this type of analysis has been the subject of numerous inquiries. The controversies begin with the characterization of the different positions assumed by the paralyzed vocal fold, which can be classified as median, para-medial, intermediate and cadaveric (in complete abduction). Although this is a classic description routinely employed in the medical clinics, there are reports that show the impossibility of defining these positions in standardized terms since there will always be the subjective factor of the examiner. (Steffenl et al, 2004) In this context, the present study did not consider data gathered from this type of analysis. However, we suggest that in future studies, such characteristics could be investigated as criteria of the DAMICORE tool in the grouping of subjects with unilateral vocal fold paralysis.

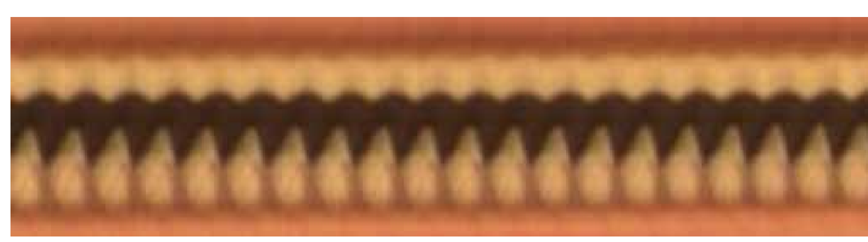
To corroborate our findings, we suggest studies with increasing numbers of samples, since an imbalance was observed regarding the gender (larger female sample) and affected side (higher prevalence of left paralyzed vocal folds). However, it is emphasized that the sample characteristics of the present study converge with the literature, which evidences a higher prevalence of the occurrence of the pathology in adult women (Schwarz et al., 2011; Gama et al., 2011; Ahmad et al., 2002.,; Mangilli et al., 2008) And in left vocal folds. (Garcia et al., 2009; Gama et al., 2011) Examples of high-speed kymographs of individuals with left (Figure 8) and right vocal fold paralysis (Figure 9) and right vocal fold paralysis (Figure 9) are shown below.

Figure 8. High-speed kymography of an individual with unilateral left vocal fold paralysis.



Source: owm elaboration of author

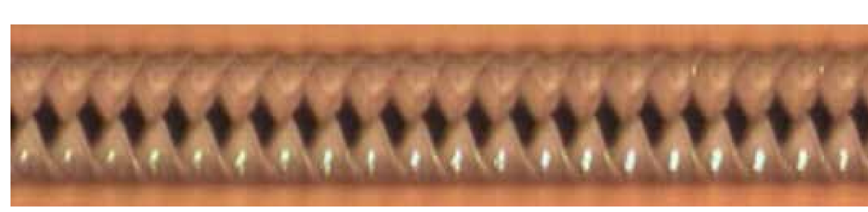
Figure 9. High-speed kymography of an individual with unilateral right vocal fold paralysis.



Source: owm elaboration of author

In addition, it is important to remember that the difficulty in establishing standard features in the analysis processes of unilateral vocal fold paralysis occurs because of the wide variety of irregularities in glottic vibrations and changes in vocal quality of the patient. (Gama et al, 2011; Busto-Crespo et al., 2016). This information makes it even more hard to identify the criteria established by the tool for grouping the data. To exemplify this difficulty, Figure 10 and 11 are presented as examples of high-speed kymographs of individuals with left vocal fold paralysis, with vibratory behavior like the healthy vocal folds subjects.

Figure 10. High-speed kymography of an individual with unilateral left vocal fold paralysis (seems normal).



Source: owm elaboration of author

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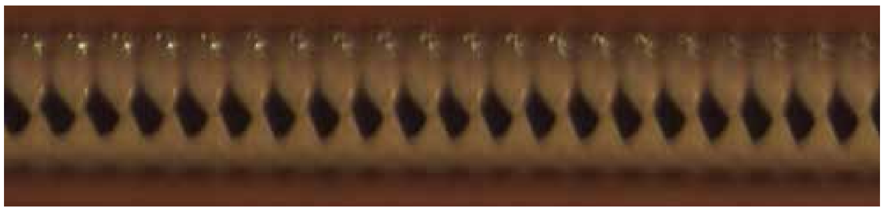
Figure 11. High-speed kymography of an individual with unilateral left vocal fold paralysis (seems normal).



Source: owm elaboration of author

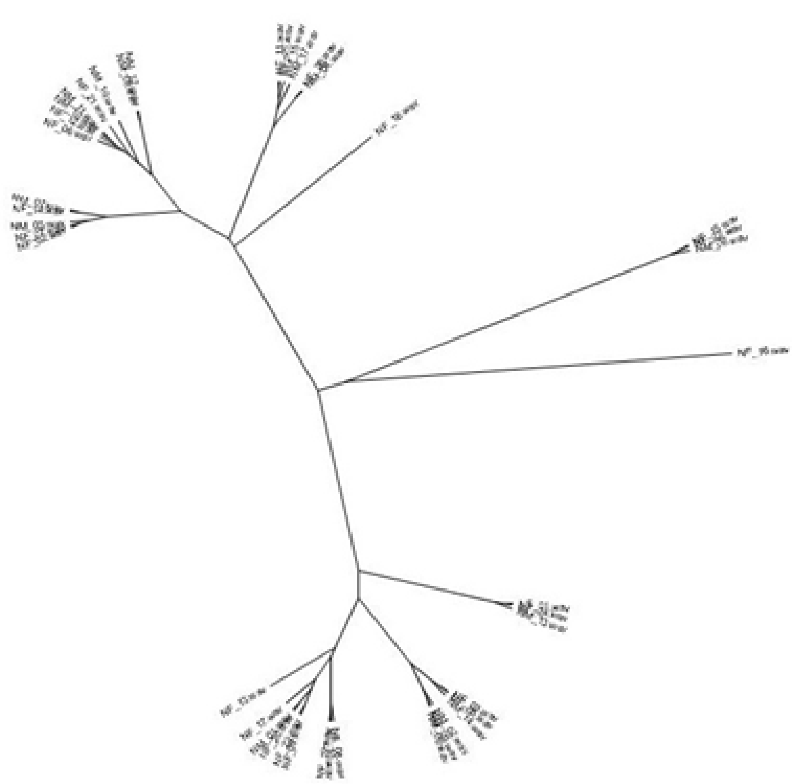
The interpretation of the “trees” generated by the DAMICORE from the laryngeal image data of unilateral vocal fold paralysis individuals in the extensions .jpg (compressor gzip) and .png (compressor zlib) showed difficulty in achieving a single criterion to justify grouping.

Acoustic signals

Voices of normal individuals

Concerning the “tree” analysis generated by DAMICORE from the acoustic signal data of healthy individuals (zlib compressor) (Figure 12). “Tree” generated from the voices data of normal individuals (acoustic signals), it was possible to observe that the clustering considered the difference between the presence of a strong noise and a weak noise (from the equipment at the time of the sample collection).

Figure 12. “Tree” generated from the voices data of normal individuals (acoustic signals). (NM: normal, male; NF: normal, female; .wav extension where the voice was stored).

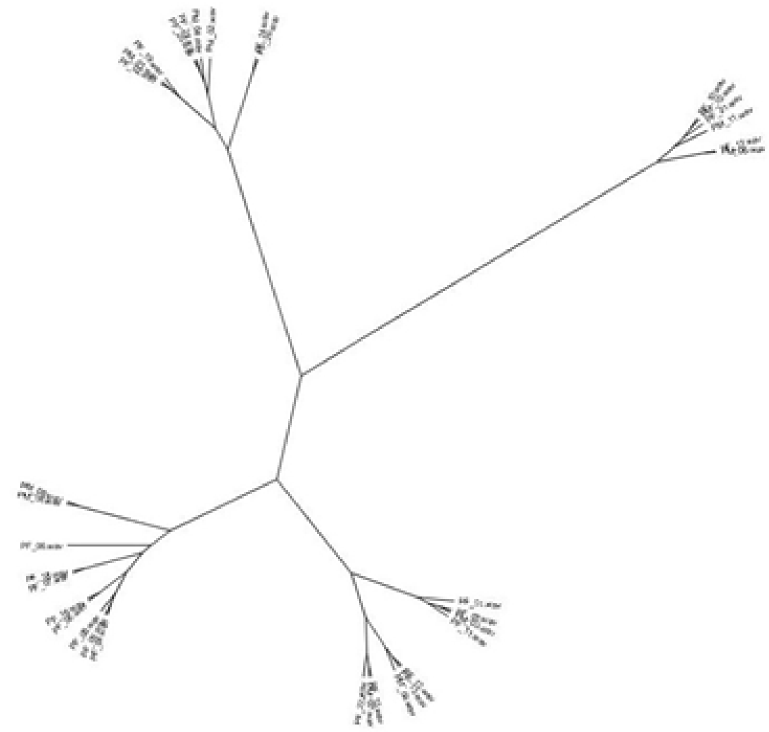


Source: owm elaboration of author

Voices of individuals with unilateral vocal fold paralysis:

A similar result was observed in the analysis performed from the acoustic signals of individuals with unilateral vocal fold paralysis (gzip compressor) Figure 13. “Tree” generated from voice data of individuals with unilateral vocal fold paralysis (acoustic signals), in which the grouping was performed by the presence of noise (from the equipment) and the presence of a voice signal.

Figure 13. “Tree” generated from voice data of individuals with unilateral vocal fold paralysis (acoustic signals). (PM: paralysis, male; PF: paralysis, female; .wav extension where the voice was stored).



Source: owm elaboration of author

Although the analysis was performed on a small number of samples, either from high-speed kymographic images or acoustic voice signals (both with a large amount of information), the DAMICORE tool was effective in performing groupings according to categories and criteria of similarities or differences between the data of the sample analyzed with accuracy.

Conclusion

In this preliminary study, it was possible to perceive that Data Mining is a promising tool for laryngeal images and acoustic signals analysis. In the analysis performed, the DAMICORE system seems to be more sensitive in identifying patterns in images comparing to acoustic signals. Considering the laryngeal images, the .bmp extension was the best option for analysis using DAMICORE, because it allows for a good compression and is the extension of the original system of High-Speed Videolaryngoscopy. In addition, it was concluded that gzip and zlib compressors were more efficient at compressing laryngeal images and acoustic voice signals.

It was also possible to conclude that the influence of artifacts (noises of the equipment in the collection of acoustic voice signals), differences in the color of laryngeal mucosa images (which were different between the subjects), and the presence of brightness in sample collection compromised the fusion to be analyzed by the tool.

At the present moment, this study presents a theoretical implication; however, from the obtained results, it is possible to delineate a future clinical implication for the classification and categorization of laryngeal data in massive quantity and automatically.

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