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Optimization, Learning Algorithms and Applications

Second International Conference, OL2A 2022
Póvoa de Varzim, Portugal, October 24–25, 2022
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OL2A INTERNATIONAL CONFERENCE

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Preface

This CCIS volume 1754 contains the refereed proceedings of the Second International Conference on Optimization, Learning Algorithms and Applications (OL2A 2022), a hybrid event held during October 24–25, 2022.

OL2A 2022 provided a space for the research community on optimization and learning to get together and share the latest developments, trends, and techniques, as well as to develop new paths and collaborations. The conference had more than three hundred participants in an online and face-to-face environment throughout two days, discussing topics associated with optimization and learning, such as state-of-the-art applications related to multi-objective optimization, optimization for machine learning, robotics, health informatics, data analysis, optimization and learning under uncertainty, and Industry 4.0.

Five special sessions were organized under the following topics: Trends in Engineering Education, Optimization in Control Systems Design, Measurements with the Internet of Things, Advances and Optimization in Cyber-Physical Systems, and Computer Vision Based on Learning Algorithms. The OL2A 2022 program included presentations of 56 accepted papers. All papers were carefully reviewed and selected from 145 submissions in an single-blind process. All the reviews were carefully carried out by a scientific committee of 102 qualified researchers from 21 countries, with each submission receiving at least 3 reviews.

We would like to thank everyone who helped to make OL2A 2022 a success and hope that you enjoy reading this volume.

October 2022

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Contents

Optimization

Statistical Analysis of Voice Parameters in Healthy Subjects and with Vocal Pathologies - HNR

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Abstract. In this article, a statistical analysis of the Harmonic to Noise Ratio (HNR) parameter was performed using the boxplot tool in the SPSS software, using the Cured Database with 901 individuals (707 pathological and 194 control) to create relevant groups, enabling the automatic identification of these dysfunctions. We analyzed whether the HNR parameter for all control and pathological subjects were compared between various voice groups, gender, vowel, and tone, no difference in HNR can be considered between the male and female gender of healthy and pathological voices. Still, there are differences between the vowels and tones of each gender. Trends indicate that this parameter is a good resource for an intelligent diagnostic system, using the vowels /a/ and /u/ in high tones.

Keywords: HNR · Statistical analysis · Cured database · Boxplot · Voice pathologies · Vocal diagnosis

1 Introduction

The diagnosis of speech pathologies is traditionally performed through video laryngoscopy and videostroboscopy exams, which are invasive, uncomfortable for patients, and expensive [1]. An alternative way to diagnose vocal pathologies is using an automatic method based on speech processing techniques. It is a non-invasive method, is fast, and can be a pre-diagnosis of such pathologies [2, 3].

There are two classic approaches in the characterization of vocal pathologies: the acoustic analysis, where features such as fundamental frequency jitter and shimmer are evaluated [4], and the spectral analysis based on noise parameters, where signal-to-noise ratio parameters and the study of the spectral energy of the signal are considered [5].

The harmonic characteristics of the voice can be measured in three parameters, Autocorrelation, NHR (Noise to Harmonic Ratio), and HNR (Harmonic to Noise Ratio), which is the object of study in this article.

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The HNR measure contains harmonic and noise components information and is sensitive to various periodicities such as jitter and shimmer [6]. This measure is the ratio of the harmonic component's energy and the noise component's energy [7]. It represents the degree of acoustic periodicity expressed in decibels dB.

The harmonic component arises from the vibration of the vocal cords, and the noisy components arise from glottal noise. It reflects the efficiency of the phonation process and characterizes the amount of noise present in the signal spectrum. Its purpose is to determine the degree of dysphonia. The lower the HNR, the more noise there is in the voice [4].

There is a strong relationship between how we perceive voice quality and the HNR. It is a relevant parameter for the identification of speech pathologies because the higher the proportion of noise, the greater the perceived hoarseness, breathing, or roughness, and the lower the HNR. That is, a low HNR indicates a high level of hoarseness, and a high HNR indicates a low level of hoarseness [8].

Laryngeal pathology can lead to poor adduction of the vocal folds, increasing the amount of random noise in vocal production. The problem with vibrating the vocal folds due to growth, paralysis of one or both vocal folds, or another type of laryngeal problem leads to more air escaping during the vibration, creating turbulent noises [9].

This paper aims to perform a statistical analysis using the boxplot tool in the SPSS software using the Cured Database [10] with 9 speech records from different individuals, of which 707 are pathological and 194 control using the HNR parameter.

The HNR measurement was analyzed for all subjects in the database (control and pathological (all pathologies)), comparing different conditions such as vowel, tone, and gender. The objective is to create relevant groups, enabling the automatic identification of these dysfunctions.

2 Methodology

This section presents the database, the pathologies used, present the HNR parameter and the statistical analysis.

2.1 Database

In the development of this paper, the Cured Database was used. This database includes several parameters. In this article, only the HNR was used, extracted from 9 voice registers corresponding to 3 vowels in 3 tones for subjects with 19 pathologies, plus control subjects.

In [10, 11], the Cured Database was built and organized based on the Saarbrucken Voice Database (SVD) [12]. The German database of speech files SVD is available online from the Institute of Phonetics of the University of Saarland. The SVD database comprises voice signals from more than 2000 people with and without pathologies. Each person has the recording of the phonemes /a/, /i/, and /u/ in low, neutral/normal, and high tones, varying between tones, and the German phrase Guten Morgen, Wie Geht es Ihnen? (Good morning, how are you?). The size of the sound files is between 1 and 3 s, recorded with 16 bits resolution and a sampling frequency of 50 kHz [4].

The Cured Database is available in.xls format through the link: http://www.ipb.pt/~joaopt/ and includes several parameters extracted from sounds produced by patients distributed in 19 speech pathologies and one control group. The parameter set of this database consists of jitter, shimmer, HNR, NHR, autocorrelation, and Mel cepstral frequency coefficients (MFCC) extracted from the sound of sustained vowels /a/, /i/ and /u/ in high, low and normal tones and a short phrase in German. The Cured Database has a total number of 901 individuals [10], In this article, the German phrase was not used, and the statistical analysis was performed only with the HNR parameter.

2.2 Pathologies Used in the Database

All pathologies from the Cured Database defined in [10] and [13, 14] were used. In Table 1, the groups studied are presented, each pathological condition was mentioned, and the total size of each sample.

2.3 HNR Parameter

The HNR is a measure that relates the periodic component (corresponding to vocal fold vibration) with the non-periodic component (glottic noise, mainly inter harmonic energy), indicating the efficiency of the phonation process [15].

There is a significant correlation between HNR values and the hoarseness and breathiness parameters [15]. The noisy component is greater the smaller the harmonic components of the issuance. Its value is expressed in dB.

The HNR is, by definition, a logarithmic measure of the ratio of energies associated with the two components, which assumes the integration of spectral power over the audible range of frequencies (see Eq. (1)) [16].

$$HNR = 10 \times \log_{10} \frac{\int_w |H(w)|^2}{\int_w |N(w)|^2} \tag{1}$$

The H(w) corresponds to the harmonic component and N(w) to the noise component.

The logarithmic measure owes its pertinence to the good correlation with the perception of sound intensity (or sound volume). In other words, the HNR attempts to measure the perception of the relationship between the periodic component of a voiced sound and its noise component.

In practice, spectrum calculation is performed using efficient techniques like the FFT. The spectrum is calculated, not as a continuous function but as a sampling of this function, so that, in practice, the integration operator gives a place for the sum (Eq. (2)) [16].

$$HNR = 10 \times \log_{10} \frac{\sum_k |H(w_k)|^2}{\sum_k |N(w_k)|^2} \tag{2}$$

An efficient low complexity algorithm to determine HNR in voiced speech audio files was presented in [17].

Table 1. Groups used for the study.

Group	Sample size male	Sample size female	Total individuals
Control	71	123	194
Vocal Cord Paralysis	67	102	169
Hyper functional dysphonia	32	95	127
Functional Dysphonia	24	51	75
Dysphonia	29	40	69
Spasmodic Dysphonia	22	40	62
Psychogenic Dysphonia	13	38	51
Chronic Laryngitis	25	16	41
Reinke's Edema	5	29	34
Vocal Cords Polyps	17	10	27
Carcinoma of the Vocal Cords	18	1	19
Hypofunctional Dysphonia	8	4	12
Hypopharyngeal Tumor	5	–	5
Laryngeal Tumor	3	1	4
Cyst	1	2	3
Intubation Granuloma	3	–	3
Granuloma	1	1	3
Hypotonic Dysphonia	2	–	2
Fibroma	–	1	1
Laryngeal Dysphonia	1	–	1

2.4 Descriptive Statistical Analysis

Every statistical analysis should start with a good descriptive analysis of the data so that, from graphs and tables, it is possible to know and better understand the data set and decide which inferential analysis should be performed. Although simple, visualizing data from charts is a powerful tool that allows quickly identifying patterns and relationships between variables in the data set. The Boxplot is one of the most valuable graphs in statistical analysis [18].

A Boxplot is a graph in which it is possible to represent the relationship between a quantitative (numerical) variable and a qualitative variable. The Boxplot's vertical axis represents the quantitative variable's values, and the horizontal axis represents the categories of the qualitative variable [19]. In the construction of the Boxplot, some percentiles (median, first, and third quartiles) are used that are little influenced by extreme values.

Initially, the normality test (Kolmogorov-Smirnov) [20] was performed in SPSS. According to Table 2, it was verified that our variable does not have a normal distribution ($p < 0.05$). In this situation, the Boxplot is the ideal statistical analysis because this type of graph must show the central tendency, the dispersion (observations between the first and the third quartile), and data showing extreme values. This set of information is helpful for comparing variables that have wide variability.

Table 2. Normality test result.

	Kolmogorov-Smirnov[a]		
	Statistic	df	Sig.
HNR_dB	.080	8028	$p < .001$

[a]Lilliefors Significance Correction

This article presents a statistical analysis of healthy and pathological voices. The HNR measure was used for all subjects in the Cured Database (control and pathological (all pathologies)), analyzing it by comparing different conditions such as vowel, tone, gender, and pathology. For the gender Analysis of HNR, a comparison was made between the three sustained vowels (/a/, /i/ and /u/) in the three tones (low, neutral, high), and the control and pathological groups were also analyzed. And all these comparisons were made by separating the male gender from the female gender. For the case of the analysis of HNR in vowels, a comparison was made in the three tones (low, neutral, high) in the groups (control and pathological) separating each sustained vowel. For the analysis of the HNR in Tones, a comparison was made for the groups separated by each tone. For the analysis of HNR in Control/Pathological groups, a general comparison of these 2 groups was made across the entire database. And finally, in a more specific way, a comparison was made of the control group with 6 pathologies (in which they have more than 50 individuals), namely: Dysphonia, Functional Dysphonia, Hyperfunctional Dysphonia, Psychogenic Dysphonia, Vocal Cord Paralysis, and Spasmodic Dysphonia.

It should be mentioned that previous to the statistical analysis, the outliers were identified and replaced by limit values (maximum and minimum), as seen in Fig. 1. The interquartile range is given by the difference between the first and third quartiles (IQR = Q3-Q1). The removal of outliers is crucial for this study because some audio files contain speech without any harmonicity resulting in HNR values being extremely low or even extremely high due to error measurements. These extreme values are unrealistic and would distort the analysis of HNR because, generally, there is a relatively low difference between healthy and pathologic voices. The extreme values are also natural but correspond to very low voice quality and are acoustically perceived.

In the different comparisons, statistically significant differences were found, which will be described in the next section.

3 Results and Analysis

A comparison of the HNR parameters is made in the first instance between the female and male genders. The records of the three vowels of the three tones in a total of 9 different records for each individual in the two control and pathological groups were used.

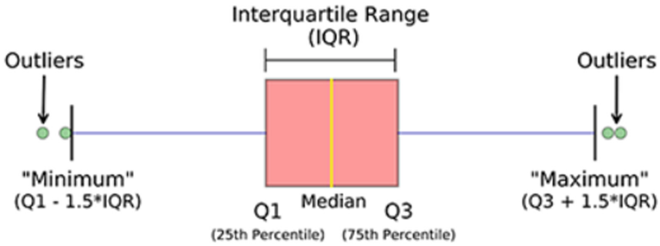

Fig. 1. Boxplot information

The boxplot graphs, the analysis of these graphs is based on [21] in which there are 3 situations. In the 1st, there is no overlap between the boxes, so there is a difference between the groups. In the 2nd, the boxes overlap without their medians, so there is probably a difference between the groups. In the 3rd, the boxes medians overlap, and no distinction can be considered between the groups.

3.1 Gender Comparison

The comparisons in Fig. 2 show a tendency of higher HNR in the vowels /u/ and /i/ compared to the vowel /a/. But, there are no statistically significant differences between vowels /u/ and /i/ in both genders. Nevertheless, vowel /a/ was a statistically significant difference in HNR to vowels /u/ and /i/ in both genders because, according to the graph, the boxes and medians overlap.

Concerning the gender comparison, no statistical difference can be observed between genders in any vowel, tone or control/pathological groups. Despite this, there is a tendency for higher HNR in all cases in female voices.

This is probably because males use a more fluid voice and the basal register, characterized by less glottal closure force, favoring a decrease in harmonics and more glottal noise.

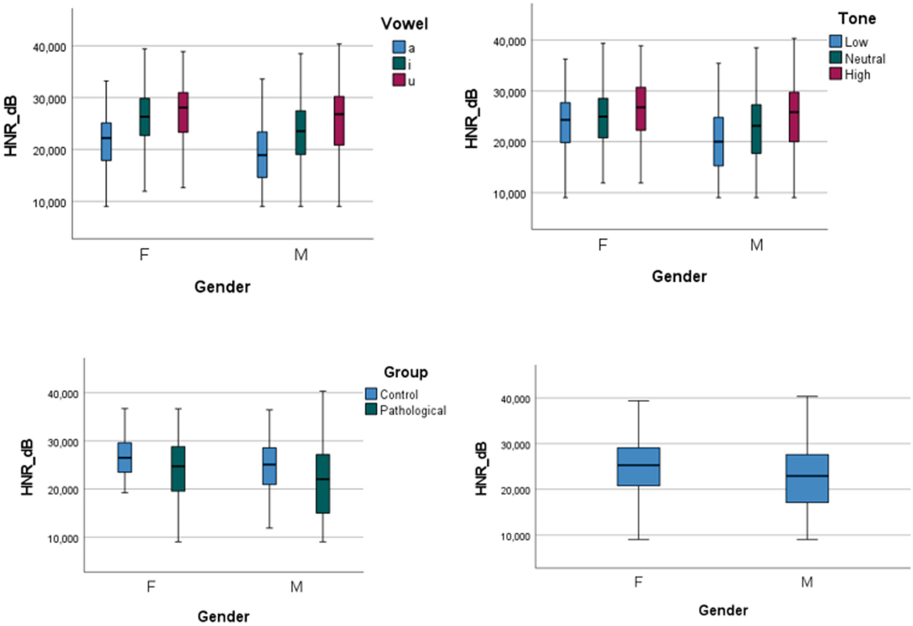

Fig. 2. Comparison of HNR between vowels, tones, control/pathological, and gender using Boxplot

3.2 Vowel and Tone Comparison

Analyzing the comparisons made in the graphs in Fig. 3, a statistically significant lower HNR in vowel /a/than in vowels /i/ and /u/at the three tones can be seen. This was already regarded in the comparison by gender in the previous section. The control group presents a statistically significant higher HNR than the pathological group in vowel /a/, but only a tendency of higher values for the other two vowels. There is no difference between /i/ and /u/ but again /a/ vowel confirms to have lower HNR.

Concerning the tone in Fig. 4, the high tone has higher HNR than the low tone. There is a tendency for HNR to increase along the vowels /a/, /i/ and /u/. There is a tendency for higher HNR in the control group than in the pathological group for the three tones.

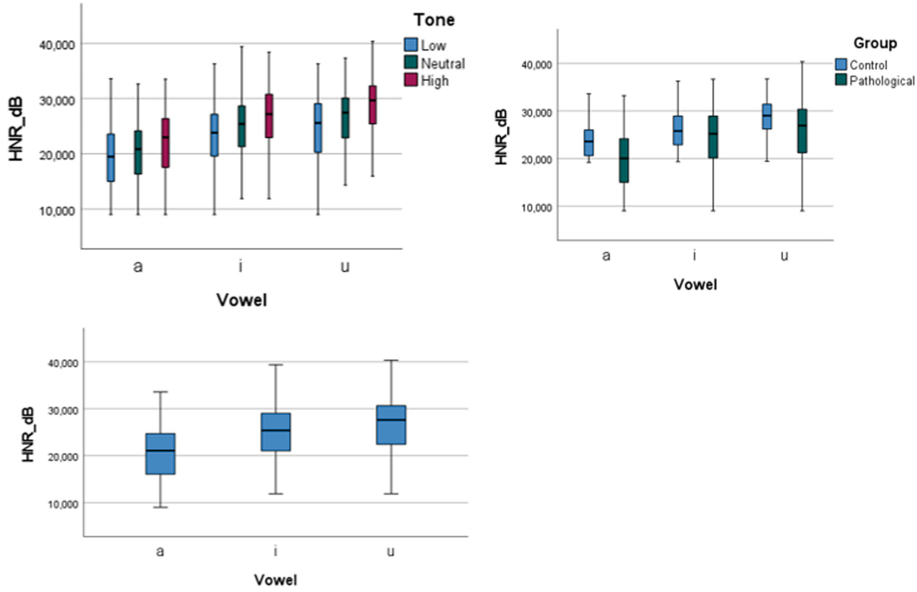

Fig. 3. Comparison of HNR Boxplot for the vowels

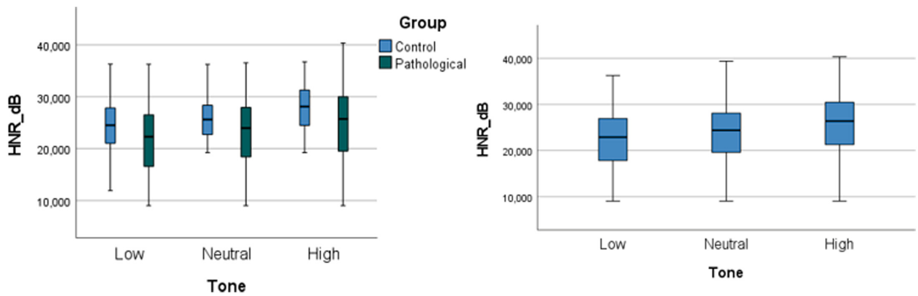

Fig. 4. Comparison of HNR Boxplot for tones

3.3 Control and Pathological Comparison

Analyzing the comparisons presented in Fig. 5, no statistically significant difference between the control and pathological groups can be considered. Still, the control group tends towards higher HNR values.

The previous analysis was done by grouping the subjects of the 19 pathologies. An attempt to separate the analysis for the pathologies with the higher number of subjects resulted in the comparison of 6 pathologies and the control group. This Boxplot shows a statistically significantly lower value of HNR for Vocal Cord Paralysis than the control group. Still, no difference was found for the other pathologies against the control group.

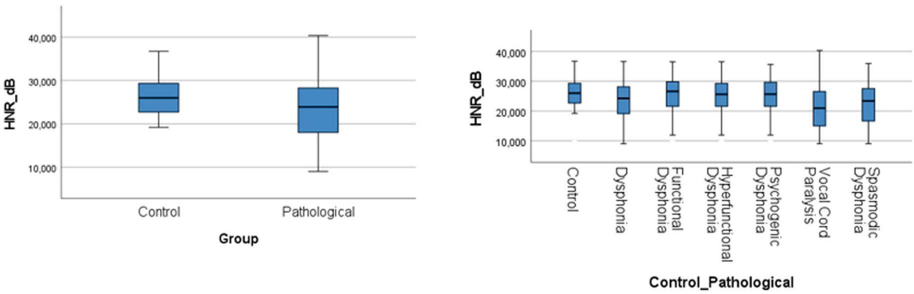

Fig. 5. Comparison of HNR Boxplot for the control-pathological

4 Discussion

Analyzing the results of previous works [22], it can be seen that the following differences were reported in the HNR:

- Higher HNR in High tone than in Neutral and LOW tone.
- Higher HNR in the vowel /u/ than in /i/ and /a/ in the control group.
- Lower HNR in the vowel /a/ than in /u/ and /i/ in dysphonia groups.

Analyzing the results of the work [23], the following can be verified about the HNR:

- There is no difference between gender (although it tends to be slightly greater for females).
- HNR is higher in the High tones (it is in line with the previous work).
- HNR is higher in the vowel /u/ (it agrees with the previous work).

Analyzing the results of the work [21], the following can be verified about the HNR:

- There is a significant difference between the control group and the Laryngeal Tumor pathology.
- There may be a difference between the control group and the pathologies: Reinke's Edema and Carcinoma.
- There is no difference between control and other pathologies.

The present work intends to continue the work started in [21–23]. In [22], the statistical analysis was performed between the control group and 4 speech pathologies only, while in the present work, 19 speech pathologies were included emphasizing the 6 with more than 50 individuals. The current work also verified the differences reported in [22]. Despite the Dysphonia group has not separated by vowels, there was a lower HNR in the vowel /a/ than in /u/ and /i/ in the pathological group.

In the current paper, the research was carried out for healthy and pathological voices. In the article [23], the statistical analysis was performed only for healthy voices. By the work [23], no significant difference was found between genders, only in healthy voices.

This non-difference from HNR is confirmed and extended to pathological voices in current research.

In [21], it was confirmed that there is no difference between the control and the other pathologies. In this article, it was verified. The specific analysis of the Laryngeal Tumor, Reinke's Edema, and Carcinoma pathologies were not performed for the reasons mentioned above. According to the criteria used to select the 6 pathologies, there are differences between the control group and the pathology of Vocal Cord Paralysis.

5 Conclusion

In this article, the Cured Database was used to compare different pathologies with the control group, differences in gender, vowels, and tones for the HNR parameter along healthy and pathological voices.

Concerning the gender comparison, the HNR parameter did not register statistical significance. No difference can be considered between male and female voices, but there is a tendency for higher HNR for female voices.

There are differences between the female vowels /a/ and the male vowel /a/, between the vowels /a/ and /i/ and between the vowels /a/ and /u/. Therefore, the HNR in the vowel /a/ is an interesting parameter for artificial intelligence tools in developing automatic techniques for pre-diagnosis speech pathologies.

Comparing vowels and tones shows a tendency towards higher values of HNR in the high tone for the three vowels. There is a tendency for higher HNR for the control than for the pathological group in the three tones (low, neutral, and high), making them interesting parameters. There are differences between the low and high tones. There is a tendency for higher HNR for the control group than the pathological group along the three vowels.

No statistically significant difference between the control and pathological groups can be considered, but the control group has a tendency for higher HNR values.

There are statistically significant differences between the control group (higher HNR) and Vocal Cord Paralysis pathology.

As future work, already undergone, a similar comparison would be extended to the other parameters, Jitter, Shimmer and Autocorrelation, present in the Cured Database.

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References

1. de Almeida, N.C.: Sistema inteligente para diagnóstico de patologias na laringe utilizando máquinas de vetor de suporte. Universidade Federal do Rio Grande do Norte, p. 119 (2010). https://repositorio.ufrn.br/jspui/handle/123456789/15149
2. Cordeiro, H.T.: Reconhecimento de patologias da voz usando técnicas de processamento da fala. Ph.D. thesis, Universidade NOVA de Lisboa, p. 142 (2016). https://run.unl.pt/bitstream/10362/19915/1/Cordeiro_2016.pdf

3. Guedes, V., et al.: Transfer learning with audioset to voice pathologies identification in continuous speech. Procedia Comput. Sci. **164**, 662–669 (2019). https://doi.org/10.1016/j.procs.2019.12.233
4. Fernandes, J.F.: Determinação da Autocorrelação, HNR e NHR para Análise Acústica Vocal, p. 84. Master's thesis at the Polytechnic Institute of Bragança (2018)
5. Cordeiro, H.: Parâmetros espectrais de vozes saudáveis e patológicas, no. June, pp. 19–22. Lisbon Polytechnic Institute (2019)
6. Murphy, P.J., Akande, O.O.: Quantification of glottal and voiced speech harmonics-to-noise ratios using cepstral-based estimation. In: Proceedings of 3rd International Conference Non-Linear Speech Processing, no. Nolisp 05, pp. 224–232 (2005)
7. De Sousa, R.J.T.: A New Accurate Method of Harmonic-To-Noise Ratio Extraction, pp. 351–356. School of Engineering, University of Porto (2011). https://doi.org/10.5220/0001552903510356
8. Franco, D.L.S.: Composição corporal, postura e produção de fala. Universidade de Lisboa (2016)
9. Freitas, S.: Avaliação Acústica e Áudio Percetiva na Caracterização da Voz Humana. Faculdade de Engenharia da Universidade do Porto, p. 251 (2012)
10. Fernandes, J., Silva, L., Teixeira, F., Guedes, V., Santos, J., Teixeira, J.P.: Parameters for vocal acoustic analysis - cured database. Procedia Comput. Sci. **164**, 654–661 (2019). https://doi.org/10.1016/j.procs.2019.12.232
11. Teixeira, J.P., Fernandes, J., Teixeira, F., Fernandes, P.O.: Acoustic analysis of chronic laryngitis statistical analysis of sustained speech parameters. In: BIOSIGNALS 2018 - 11th International Conference on Bio-Inspired Systems and Signal Processing. Proceedings; Part 11th International Joint Conference on Biomedical Engineering Systems and Technologies, BIOSTEC 2018, vol. 4, no. Biostec, pp. 168–175 (2018). https://doi.org/10.5220/0006586301680175
12. Martínez, D., Lleida, E., Ortega, A., Miguel, A., Villalba, J.: Advances in Speech and Language Technologies for Iberian Languages. Communications in Computer and Information Science, vol. 328, pp. 99–109 (2014). https://doi.org/10.1007/978-3-642-35292-8
13. Passerotti, G.: Doenças Benignas Da Laringe, pp. 1–18 (2005)
14. Guimarães, F.: Patologia da Mucosa das Cordas Vocais. Faculdade de Medicina de Lisboa Universidade de Lisboa, pp. 1–28 (2018)
15. Faria, J.C.F.: Avaliação Complementar da Voz através de Medidas Acústicas de longo Termo em Vozes Disfonicas. Escola Superior De Saúde Politécnico Do Porto (2020)
16. Lopes, J.M.D.S.: Ambiente de análise robusta dos principais parâmetros qualitativos da voz. Faculdade de Engenharia da Universidade do Porto, p. 71 (2008). http://repositorio-aberto.up.pt/bitstream/10216/58997/1/000136648.pdf
17. Fernandes, J., Teixeira, F., Guedes, V., Junior, A., Teixeira, J.P.: Harmonic to noise ratio measurement - selection of window and length. Procedia Comput. Sci. **138**, 280–285 (2018). https://doi.org/10.1016/j.procs.2018.10.040
18. IBM and SPSS: IBM SPSS statistics base 25, p. 341 (2017)
19. Reis, E.A.: Análise Descritiva de Dados. Universidade Federal de Minas Gerais (2002)
20. Miranda, A.: Testes Não Paramétricos, pp. 1–29 (2020)
21. de Oliveira, A.A., Dajer, M.E., Fernandes, P.O., Teixeira, J.P.: Clustering of voice pathologies based on sustained voice parameters. In: BIOSIGNALS 2020 - 13th International Conference on Bio-Inspired Systems and Signal Processing. Proceedings; Part 13th International Joint Conference Biomedical Engineering Systems and Technologies, BIOSTEC 2020, no. Biostec, pp. 280–287 (2020). https://doi.org/10.5220/0009146202800287

22. Teixeira, J.P., Fernandes, P.O.: acoustic analysis of vocal dysphonia. Procedia Comput. Sci. **64**, 466–473 (2015). https://doi.org/10.1016/j.procs.2015.08.544
23. Teixeira, J.P., Fernandes, P.O.: Jitter, Shimmer and HNR classification within gender, tones and vowels in healthy voices. Procedia Technol. **16**, 1228–1237 (2014). https://doi.org/10.1016/j.protcy.2014.10.138