Original Article

https://doi.org/10.1590/2317-6431-2019-2194

Audiology Communication Research
ISSN 2317-6431

Spectrographic classification of the vocal signal: relation with laryngeal diagnosis and auditory-perceptual analysis

Classificação espectrográfica do sinal vocal: relação com o diagnóstico laríngeo e a análise perceptivo-auditiva

Leonardo Wanderley Lopes[1,2], Itacely Marinho da Silva[1], Estevão Silvestre da Silva Sousa[1], Allan Carlos França da Silva[1], Maxsuel Avelino Alves de Paiva[1], Emanuel Gustavo Rodrigues Diniz[1], Priscila Oliveira Costa Silva[1]

ABSTRACT

Purpose: To verify whether there is an association between the presence of laryngeal alteration, auditory-perceptual analysis of vocal quality, and the spectrographic classification of the vocal signal in individuals with voice disorders. **Methods:** 478 patients with voice disorders participated in the study. A recording of the sustained vowel /Ɛ/ and a medical examination were performed to establish a laryngeal diagnosis. The vowel spectrograms were used to classify the signals into type I, II, III and IV. **Results:** Voices of individuals without laryngeal disorders were predominantly classified as type I and type II, while signals of individuals with laryngeal disorders were classified as types III and IV. Deviated voices were predominantly classified as type II, while the signals of patients with vocal deviation were predominantly categorized as types II and III. Only the signals of individuals with vocal deviation were classified as type IV. Type III and IV signals showed higher values for the general degree of deviation and for degrees of roughness and breathiness in relation to type I and type II signals. Type IV signals showed a higher general degree and degrees of roughness and breathiness compared to type III signals. Only type IV signals showed higher values in the degree of tension compared to types I, II and III signals. **Conclusion:** There is an association between the presence of laryngeal alteration, auditory-perceptual analysis, and the spectrographic classification of the vocal signal in individuals with voice disorders.

Keywords: Acoustics; Voice; Voice disorders; Sound spectrography; Speech therapy

RESUMO

Objetivo: Verificar se existe associação entre a presença de alteração laríngea, a análise perceptivo-auditiva da qualidade vocal e a classificação espectrográfica do sinal vocal em indivíduos com distúrbio de voz. **Métodos:** Participaram 478 pacientes com distúrbios de voz. Foi realizada gravação da vogal /Ɛ/ sustentada e o exame médico para estabelecimento de diagnóstico laríngeo. Os espectrogramas da vogal foram utilizados para classificação dos sinais em Tipo I, II, III e IV. **Resultados:** Vozes de indivíduos sem alteração laríngea foram classificadas, predominantemente, como Tipo I e Tipo II, enquanto sinais de indivíduos com alteração laríngea foram classificados nos Tipos III e IV. Vozes desviadas foram classificadas, predominantemente, como Tipo II, enquanto os sinais de pacientes com desvio vocal foram categorizados, predominantemente, como Tipos II e III. Apenas os sinais de indivíduos com desvio vocal foram classificados como Tipo IV. Sinais Tipo III e IV apresentaram valores mais elevados no grau geral do desvio e nos graus de rugosidade e soprosidade, em relação aos sinais Tipo I e Tipo II. Os sinais Tipo IV apresentaram maior grau geral e graus de rugosidade e soprosidade, em comparação aos sinais Tipo III. Apenas os sinais Tipo IV apresentaram valores mais elevados no grau de tensão, em relação aos sinais Tipo I, II e III. **Conclusão:** Há associação entre a presença de alteração laríngea, a análise perceptivo-auditiva e a classificação espectrográfica do sinal vocal em indivíduos com distúrbio de voz.

Palavras-chave: Acústica; Voz; Distúrbios da voz; Espectrografia do som; Fonoaudiologia

Study carried out at Departamento de Fonoaudiologia, Universidade Federal da Paraíba – UFPB – João Pessoa (PB), Brasil.
[1]Departamento de Fonoaudiologia, Universidade Federal da Paraíba – UFPB – João Pessoa (PB), Brasil.
[2]Programa Associado de Pós-graduação em Fonoaudiologia – PPGFON/UFPB/UFRN, Universidade Federal da Paraíba – UFPB, Universidade Federal do Rio Grande do Norte – UFRN – João Pessoa (PB), Brasil.
Conflict of interests: No.
Authors' contribution: All authors were responsible for preparing the manuscript. LWL was responsible for supervising the research; IMS, ESSS, ACFS, MAAP and EGRD were responsible for collecting data and writing the manuscript; POCS was responsible for reviewing the manuscript.
Funding: None.
Corresponding author: Leonardo Wanderley Lopes. E-mail: lwlopes@hotmail.com
Received: May 22, 2019; **Accepted:** January 31, 2020

INTRODUCTION

Voice production is multidimensional and involves the understanding of physiological and biomechanical aspects of vocal production and the impacts caused by the voice on the interlocutor. Thus, it is recommended that the assessment be able to map the different dimensions of vocal production, including auditory-perceptual, laryngeal, aerodynamic, acoustic, and self-assessment data[1]. In this context, auditory-perceptual analysis and acoustic evaluation are the main methods for characterizing vocal quality and monitoring it throughout the treatment.

The acoustic evaluation may involve the descriptive analysis of visual patterns, such as broadband and narrowband spectrogram, phonation deviation diagram and long term spectrum, and/or the extraction of energy, disturbance and noise measurements in the vocal signal[1]. The visual inspection of the narrow band spectrographic tracing is one of the most used procedures clinically since it allows a qualitative evaluation of the signal regardless of the degree of aperiodicity and noise present in the emission[2].

The spectrogram is a three-dimensional graph that represents the frequency domain on the vertical axis, the time domain on the horizontal plane, and the amplitude of the sound wave components by the color contrast in the tracing[2]. In general, the interpretation of spectrographic tracing depends on the visual description of the observed characteristics and the association of these characteristics with the auditory-perceptual analysis of vocal quality and data from laryngeal examination[3].

There are two descriptions available in the literature to classify vocal signals based on the narrow band spectrographic tracing, namely that of Yanagihara[4] and Titze[5]. Yanagihara[4] classified the signals into types I, II, III and IV using as criteria the regularity of harmonics, the presence of noise in different frequency ranges, and the relationship between the harmonic structure and the noise present in the tracing. The classification proposed by Titze[5] is based on the model of non-linear dynamics of vocal production, categorizing the signals into type I, II and III considering as the main criterion the presence of bifurcation (subharmonics) in the domain of time and noise in the domain of frequencies, both arising from changes in the vibratory pattern of vocal folds. Later, Sprecher et al.[6] proposed to add the type IV signal to the original classification of Titze. The type IV signal corresponds to the absence of a periodic structure in the tracing whose source of production is the turbulent transglottic noise dissipated in the vocal tract and not the vibratory movement of the vocal folds[6].

It should be noted that the classification of Titze[5] is based on the vibratory patterns of the vocal folds, and that there is no correspondence between the typology of the signal in the spectrographic tracing and the deviation of the vocal quality perceived aurally, as well as between the type of signal and the presence of structural or functional changes in the larynx. Obviously, the author's objective was not to develop a script for vocal assessment but to establish criteria for choosing the most reliable acoustic analysis method for investigating each type of signal.

Thus, considering that the type of signal can be an important criterion to direct the type of acoustic analysis to be performed and that, in addition, there is the possibility of using the classification of Titze[5] and Sprecher et al.[6] together to categorize the signals of clinically evaluated patients, the present study aims to verify whether there is an association between the presence of laryngeal alteration, the auditory-perceptual analysis of vocal quality, and the spectrographic classification of the vocal signal in individuals with voice disorders.

There are two hypotheses that support this study: 1) Patients with vocal complaints and laryngeal alterations are predominantly classified as types III and IV, while the signals of individuals with vocal complaints without laryngeal alterations are predominantly classified as type I and II; 2) there is an association between the auditory-perceptual analysis of vocal quality (general degree and degrees of roughness, breathiness and tension) and the type of vocal signal.

The findings of the present study may elucidate important questions about vocal input and output by verifying whether the type of spectrographic tracing is associated with the presence of laryngeal alterations and deviation of vocal quality, as well as whether there is an association between the typology of the signal and the degree of vocal deviation. In addition, it will be possible to understand whether the typology proposed by Titze[5] and Sprecher et al.[6] could be indicated for monitoring individuals with voice disorders during vocal therapy or before and after surgical intervention in the larynx. The possibility of using a standardized typology may facilitate communication between clinicians in the process of vocal assessment and monitoring.

METHODS

Study design

This is a cross-sectional, descriptive, observational study approved by the Research Ethics Committee of the Health Sciences Center of the Federal University of Paraíba (UFPB) under the opinion no. 508200/13. All participants answered an Informed Consent (IC) authorizing participation in the research.

Sample

The samples comprised patients seen at the Voice Laboratory of the Speech Therapy Department at UFPB between April 2012 and April 2017. The individuals were selected according to the following eligibility criteria: age over 18 years, vocal complaints, positively responding to the question "do you think you have a voice problem at the moment?", record of the sustained vowel /Ɛ/ with a minimum duration of three seconds, and otorhinolaryngological report on the laryngeal visual examination. Individuals who used the voice professionally, whether sung or spoken, were excluded from the research because individuals with vocal training can implement glottal and supraglottic adjustments that modify the acoustic signal even in the presence of laryngeal injury or deviation of vocal quality[7]. Thus, 478 individuals participated, 357 women and 121 men, with an average age of 41.07±13.73.

All selected samples correspond to the recording at the initial moment of the vocal assessment before performing speech therapy.

Data collection procedures

The vocal samples used in this research were collected using the software *Fonoview*, version 4.5, from CTS Informática, a Dell *all-in-one* desktop, and a Sennheiser unidirectional cardioid microphone, model E-835, placed on a pedestal and coupled to a Behringer preamplifier, model U-Phoria UMC 204. The patients emitted the sustained vowel /ɛ/ in a frequency and intensity self-reported as usual. The voice collection took place in a recording booth with acoustic treatment and noise below 50 dB SPL. A sampling rate of 44,000 Hz was used with 16 bits per sample.

Initially, all selected samples were accessed in the software *Fonoview*, generating a narrow band spectrogram with 40 ms windowing, 2.5 ms update time, 60 dB dynamic range, and 7,500 Hz frequency limit. At that moment, a visual inspection of the tracing was carried out to verify whether the duration of the vowel produced corresponded to the minimum time of the three seconds established in this research. In this way, the signals whose duration was equal to or greater than three seconds were selected and edited by manually cutting the initial and final seconds and keeping only the central three seconds of emission. Next, the spectrographic tracing referring to the edited signal was saved in .jpeg format for later analysis. The entire editing procedure was performed using the software *Fonoview*.

Five judges, students of Speech Therapy, were trained to perform the visual inspection of the spectrographic tracing and classify it into type I, II, III or IV according to the recommendations of Titze[5] and Sprecher et al.[6]. The training was carried out by a speech therapist specialized in voice with over 15 years of experience in vocal assessment and visual inspection of narrow band spectrographic tracing. For the training, four spectrograms corresponding to the types of signals studied[6] were used as anchor stimuli, as shown in Figure 1. Subsequently, the students were trained to recognize the typology of signals in 120 spectrograms corresponding to the vocal signals of patients with different voice disorders and healthy vocal individuals previously selected in the database and used in a previous study[2].

After training, the five students received 478 files of narrow band spectrograms in .jpeg format together with the four anchor stimuli of each signal, as mentioned above. They were instructed to make a visual inspection of the tracing and classify the signal according to the typology and criteria proposed by Titze[5] and Sprecher et al.[6]. Thus, the signals were classified as:

- **Signal type I:** almost periodic, without modulations or subharmonics, rich series of harmonics defined up to 4 KHz, regularity in the layout, absence or presence of low amplitude noise in relation to the harmonic structure;
- **Signal type II:** oscillating between almost periodic and aperiodic, presence of modulations and bifurcations, presence of clearly defined subharmonics, intermittent (duration ≤ 1s), and intensity close to the intensity of f0;
- **Signal type III:** aperiodic, chaotic and with finite dimension, presence of noise energy between low frequency harmonics, greater definition in the first low frequency harmonics instead of replacing the high frequency harmonics with diffuse noise, energy concentration below 1.5 KHz;
- **Signal type IV:** aperiodic and chaotic, infinite dimension, and predominance of noise in relation to the harmonic structure in the entire frequency range.

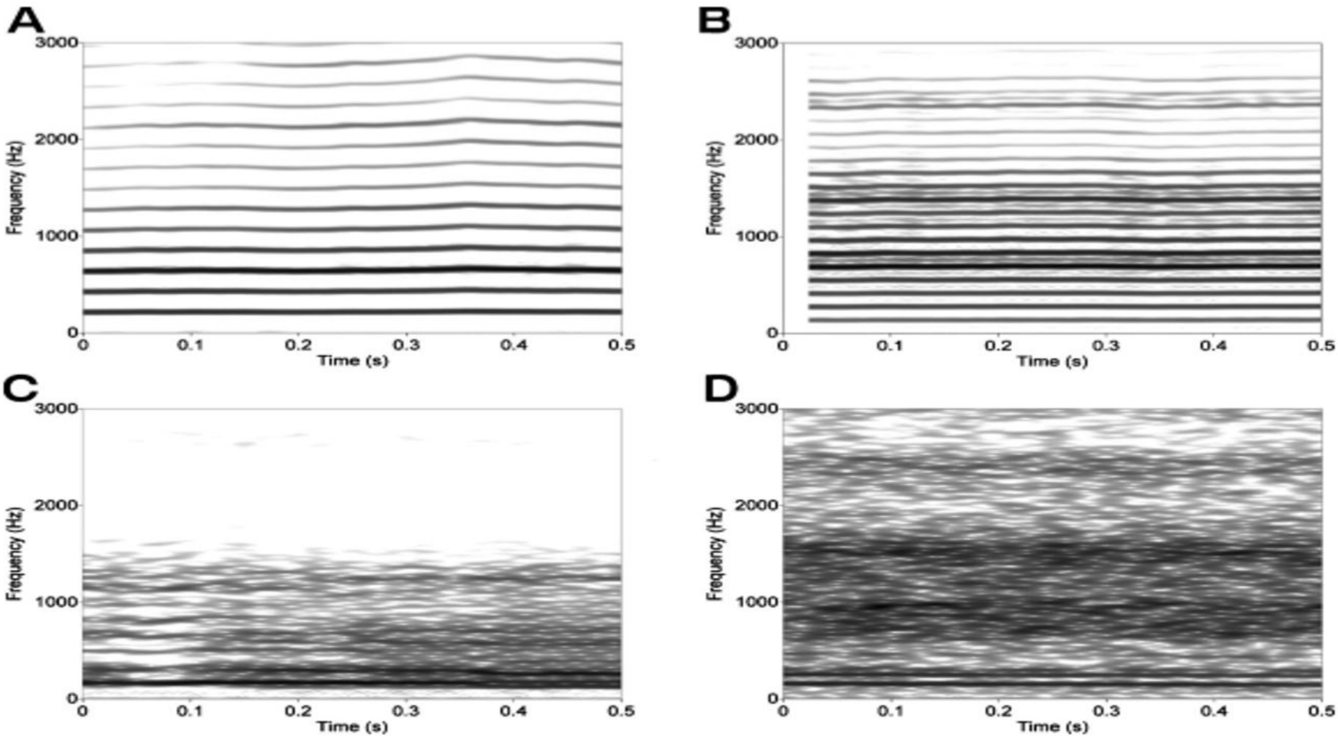

Figure 1. Spectrograms extracted based on voice samples. Figures (A), (B), (C) and (D) show, respectively, signals of types 1, 2, 3 and 4. Spectrograms (A) and (D) are for female voices, while (B) and (C) are for male voices[6]

The analyses were performed independently by the students and the answers were typed directly into a Microsoft Excel spreadsheet. For the final classification of the signals, the results of the students' judgments were considered. As a criterion for the classification of signals, the typology indicated by at least four of the five evaluators was adopted. In cases where there was a great disagreement between evaluators, they were asked to jointly evaluate such signals, including a discussion of the classification criteria, visual inspection, comparison with anchor stimuli and, finally, signal classification.

Subsequently, a confirmatory classification of the typology of the signals was carried out. To this end, the same speech therapist who trained the academics was recruited. He reanalyzed all spectrographic traces and subsequently compared his classification with the results obtained by the academics. In cases where there was divergence in the classification, the students and the speech therapist were invited to discuss the classification and establish a new classification by consensus. Thus, 19 signals were classified as type I, 314 signals as type II, 123 signals as type III, and 22 signals as type IV.

For the auditory-perceptual analysis, a visual analogue scale (VAS) from 0 to 100 mm was used to assess the degree of vocal deviation (VD) and the degrees of roughness (DR), breathiness (DB) and tension (DT) of the sustained vowel emission. The analysis was carried out by three Speech-Language Pathologists specialized in voice, who were advised that the marking closer to 0 represented more socially acceptable voices produced in a more natural way with less effort, noise or unstable condition. Conversely, markings closer to 100 represented less socially accepted voices with a greater perception of effort, noise or instability. They were also instructed that roughness corresponded to the presence of vibratory irregularity, breathiness was related to the escape of audible air in the emission, and tension corresponded to the perception of vocal effort throughout the emission. The auditory-perceptual parameters of roughness, breathiness and tension were chosen to characterize the signals in this study because they are universally used to characterize voice quality deviation[8] and because they have known correlates in the physiological and acoustic planes.

For evaluation, each emission of the sustained vowel was played three times through a speaker at a comfortable intensity self-reported by the evaluator. After each presentation, the judges assessed VD, DR, DB and DT, followed by identification of vocal quality (type of deviation) prevalent in deviated voices (rough, breathy, or tense).

At the end of the perceptual evaluation session, 20% (96 signals) of the samples were repeated at random for an analysis of the reliability of the judge's evaluation using the Cohen's Kappa coefficient. The judge with the highest coefficient (0.80) was selected, indicating a good reliability of the evaluator.

The cutoff values of the VAS[9] were used to classify voices regarding the presence of vocal deviation (VD). Thus, 97 voices were classified as having a normal vocal quality variability (NVQV) (VD $\leq$ 35.5 mm) and 381 voices were categorized as deviated (VD > 35.5 mm). All individuals with NVQV showed no structural or functional laryngeal alterations. Of the patients with deviated voices, only 11 received reports of absence of structural or functional changes in the larynx, while the remaining 370 received reports of structural or functional changes in the larynx. Then, the VD values in the VAS were used to classify the signals into four groups based on the cutoff values indicated in the literature[9]: 97 voices with NVQV (0-35.5 mm), 209 voices with grade 2 (35.6-50.5 mm), corresponding to a slight to moderate deviation, 145 voices with grade 3 (50.6-90.5 mm), corresponding to a moderate deviation, and 27 voices with grade 4 (90.6-100 mm), corresponding to an intense deviation.

It should be noted that the reference study[9] used for the Brazilian reality to determine the VAS cutoff values used as a speech task only uses counts from one to ten (chained speech). Although this may be a limitation to the present study, we decided to use the cutoff values proposed by Yamasaki et al.[9] because these authors used only the four degrees of deviation considered internationally (healthy or NVQV, mild to moderate, moderate and intense), and because it is the main Brazilian reference for the cutoff values used for this classification.

Finally, the data related to the result of the patient's visual laryngeal examination were consulted in the patient's medical record and described in Chart 1.

It should be noted that in the present study, all individuals had vocal complaints regardless of the presence/absence of laryngeal alterations and/or deviation in vocal quality. In addition, patients with voice disorders secondary to neuromuscular disease also received diagnostic confirmation by the neurologist.

Data analysis

Descriptive statistical analysis was performed for all variables. The Chi-square test (x^2) was used to compare the analysis of the types of signals according to the presence of laryngeal alterations and the presence of vocal deviation. The ANOVA test was used to compare the averages of the degree of vocal deviation and the degrees of roughness, breathiness and tension between the different types of vocal signals. In cases where there was an interaction between the type of signal and the averages of auditory-perceptual measurements, the Scheffé test was performed to compare the types of signals

Chart 1. Description of laryngeal diagnoses of the patients included in this study

LARYNX DIAGNOSIS	n (%)
Absence of structural or functional changes in the larynx	108 (22.59%)
Vocal nodules	101 (21.12%)
Inconclusive laryngological report	61 (12.76%)
Voice disorder secondary to laryngopharyngeal reflux	45 (9.41%)
Vocal cyst	41 (8.57%)
Middle-posterior triangular cleft	36 (7.53%)
Voice disorder secondary to neuromuscular disease	26 (5.43%)
Unilateral vocal fold paralysis	21 (4.39%)
Vocal fold polyp	20 (4.18%)
Vocal groove	8 (1.67%)
Reinke's edema	5 (1.04%)
Vascular dysgenesis	3 (0.62%)
Granuloma in the vocal process	2 (0.05%)
Carcinoma *in situ* in the vocal folds	1 (0.20%)

Subtitle: n = number of individuals; % = percentage two by two. All analyses were performed using the *Statistical Package for Social Sciences* (SPSS, version 21.0), with a 5% significance level.

RESULTS

Initially, the frequency distribution of the voices of individuals with and without laryngeal alterations was compared according to the different types of vocal signals (Table 1). There was a difference in the proportion of the type of signal due to the presence/absence of laryngeal alterations. The vocal signals of individuals without laryngeal disorders were predominantly classified as type I and type II. In turn, the vocal signals of individuals with laryngeal disorders were predominantly classified as types III and IV.

Then, the frequency of voice distribution of individuals with and without vocal deviation was compared according to the type of signal. There was a difference in the proportion of the type of signal in function of the presence/absence of vocal deviation. The signals corresponding to individuals without vocal deviation were predominantly classified as type II, while the signals of patients with vocal quality deviation were predominantly categorized as types II and III (Table 2). Only the signals of individuals with vocal deviation were classified as type IV.

Then, the averages of the degree of vocal deviation and degrees of roughness, breathiness and tension between the different types of signals were compared (Table 3). There was a difference in all auditory-perceptual measurements analyzed (Table 3).

Considering that there was an interaction between the auditory-perceptual measurements and the type of signal, we proceeded with the *post hoc* analysis to compare the groups two by two. Type III and IV signals showed higher values of vocal deviation degree and degrees of roughness and breathiness in relation to type I and type II signals (Table 4). In addition, type IV signals showed a higher degree of vocal deviation and degrees of roughness and breathiness compared to type III signals (Table 4). Only type IV signals showed higher values in the degree of tension compared to types I, II and III signals.

Table 1. Proportion of the type of vocal signals in function of the presence or absence of laryngeal alterations

	WITHOUT LARYNGEAL ALTERATION		WITH LARYNGEAL ALTERATION		TOTAL	P-VALUE
	N	%	n	%		
TYPE I	6	5.5	13	3.5	19	<0.001*
TYPE II	92	85.2	222	60.0	314	<0.001*
TYPE III	9	8.3	114	30.8	123	<0.001*
TYPE IV	1	0.93	21	5.6	22	<0.001*
TOTAL	108	100	370	100	478	

Chi-square test; *Significant values (p<0.05)
Subtitle: n = number of individuals; % = percentage

Table 2. Proportion of the type of vocal signals in function of the presence or absence of voice quality deviation

	WITHOUT VOCAL DEVIATION		WITH VOCAL DEVIATION		TOTAL	P-VALUE
	n	%	n	%		
TYPE I	10	10.3	9	2.4	19	<0.001*
TYPE II	80	82.5	234	61.4	314	<0.001*
TYPE III	7	7.2	116	30.4	123	<0.001*
TYPE IV	0	0	22	5.8	22	<0.001*
TOTAL	97	100	381	100	478	

Chi-square test; *Significant values (p<0.05)
Subtitle: n = number of individuals; % = percentage

Table 3. Comparison of averages of the intensity of vocal deviation and the degrees of roughness, breathiness and tension among the different types of vocal signals

VARIABLES	CLASSIFICATION OF SPECTROGRAMS								P-VALUE
	TYPE I		TYPE II		TYPE III		TYPE IV		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
VAS-VD	41.42	10.33	44.77	9.83	56.28	15.04	81.41	14.28	<0.001*
VAS-DR	37.89	11.29	40.07	11.70	51.25	15.84	73.95	13.90	<0.001*
VAS-DB	26.95	20.08	27.99	19.61	42.61	20.83	65.14	20.97	<0.001*
VAS-DT	24.63	15.35	27.75	15.25	31.35	20.86	58.18	26.53	<0.001*

ANOVA test; *Significant values (p <0.05)
Subtitle: VAS = Visual analog scale; SD = Standard deviation; VD = general voice degree; DR = degree of roughness; DB = degree of breathiness; DT = degree of tension

Table 4. *Post hoc* analysis of different types of signals in function of vocal deviation intensity and degrees of roughness, breathiness and tension

VARIABLE	CLASSIFICATION OF SPECTROGRAM	MEAN DIFFERENCE	P-VALUE
VAS-VD	TYPE I x TYPE III	-14.864	<0.001*
	TYPE I x TYPE IV	-39.98	<0.001*
	TYPE II x TYPE III	-11.51	<0.001*
	TYPE II x TYPE IV	-36.63	<0.001*
	TYPE III x TYPE IV	-25.12	<0.001*
VAS-DR	TYPE I x TYPE III	-13.35	<0.001*
	TYPE I x TYPE IV	-36.06	<0.001*
	TYPE II x TYPE III	-11.18	<0.001*
	TYPE II x TYPE IV	-33.88	<0.001*
	TYPE III x TYPE IV	-22.70	<0.001*
VAS-DB	TYPE I x TYPE III	-39.06	<0.001*
	TYPE I x TYPE IV	-38.18	<0.001*
	TYPE II x TYPE III	-14.61	<0.001*
	TYPE II x TYPE IV	-37.14	<0.001*
	TYPE III x TYPE IV	-22.52	<0.001*
VAS-DT	TYPE I x TYPE IV	-19.56	<0.001*
	TYPE II x TYPE IV	-30.42	<0.001*
	TYPE III x TYPE IV	-26.83	<0.001*

Scheffé test; *Significant values (p<0.05)
Subtitle: VAS = Visual analog scale; VD = general voice degree; DR = degree of roughness; DB = degree of breathiness; DT = degree of tension

DISCUSSION

The narrow band spectrographic analysis allows evaluating vocal signals with a wide deviation range from the quasi-periodic to the most aperiodic[2]. Thus, the acoustic inspection of spectrographic tracing can provide qualitative and quantitative data of the signal, integrating it with auditory-perceptual and laryngeal information[10]. Standardizing the signal typology in clinical assessment reports can be an important strategy for monitoring vocal quality and evaluating the outcomes of clinical (therapeutic or drug) or surgical interventions in patients with voice disorders.

In this study, we verified whether there was an association between the presence of laryngeal alteration, auditory-perceptual analysis of vocal quality, and the spectrographic classification of the vocal signal in individuals with voice disorders. Thus, the initial hypothesis was confirmed, according to which patients with vocal complaints and laryngeal alterations are predominantly classified as types III and IV while the signals of individuals with vocal complaints and without laryngeal alteration are predominantly types I and II.

The classification of vocal signals proposed by Titze[5] and Sprecher et al.[6] is based on the changes in the characteristics of the vocal signal due to changes in the vibratory pattern of the vocal folds. Thus, variations in subglottic pressure, transglottic airflow, longitudinal and median tension between vocal folds, and collision forces between vocal folds modify the characteristics of the vocal signal. Thus, the presence of alterations or structures in the larynx could justify the spectrographic characteristics related to type III signals, which include noise between low frequency harmonics, reduced number of harmonics in the entire frequency range, greater definition of the first harmonics (in low frequencies), replacement of harmonics by noise at high frequencies, and harmonic energy concentration below 1.5 KHz[5]. In turn, type 4 signals are characterized by a predominance of noise over the harmonic structure in the entire frequency range[6].

Considering that in the sample of this research patients with laryngeal alterations had different diagnoses, with cases ranging from incomplete glottic closure to cases of phonotraumatic lesions and neurological etiology (central or peripheral), it is possible to understand the greater proportion of types III and IV.

It should be noted that a considerable number of vocal signals of patients with laryngeal alteration was classified as type II. The tracing related to these signals is characterized by the irregularity of the harmonics in the time domain, presence of subharmonics with duration ≤ 1, and less definition of the harmonic structure up to 4 KHz[5]. This finding may indicate that some patients with vocal complaints and laryngeal alterations may present slight changes in the vocal signal, reinforcing the importance of integrating data of different types (laryngeal, perceptual, aerodynamic, acoustic, and self-assessed) in the assessment of patients with voice disorders.

Obviously, this study did not intend to analyze the classification of signals among patients with different laryngeal diagnoses. Thus, it is not possible to state whether there is a specific diagnostic category associated with these signals classified as type II. Future studies using this same database can elucidate this issue and verify whether there is a greater proportion of any specific diagnostic group classified as type II. In turn, it is emphasized that there is not necessarily a *continuum* deviation of the vocal signal due to the laryngeal diagnosis since several factors such as the individual's vocal demand, the interaction of organic and behavioral factors, the configuration/location of the lesion, the glottal closure pattern and the behavior of the supraglottis in vocal production can modify the relationship between vocal input and output[6]. An information that reinforces this statement is the fact that 12 signals of patients with laryngeal alterations were classified as type I in the present study.

The hypothesis according to which there is an association between the auditory-perceptual analysis of vocal quality (general degree and degrees of roughness, breathiness and tension) and the type of vocal signal was also confirmed. The signals of patients with vocal quality deviation were predominantly classified as types II, III and IV, while the signals of patients without vocal quality deviation were predominantly categorized as type II. Type III and IV signals showed higher values of vocal deviation degree and degrees of roughness and breathiness in relation to type I and type II signals. In addition, type IV signals showed a higher degree of vocal deviation and degrees of roughness and breathiness compared to type III signals. Only type IV signals showed higher values in the degree of tension compared to types I, II and III signals.

Thus, the increase in the degree of vocal deviation seems to reflect the signal's spectrographic classification. The greater the degree of vocal deviation, the greater the proportion of signals classified as types III and IV. The qualitative analysis of mean and SD values of the parameters measured in the auditory-perceptual evaluation shows that there is an increase in the general degree and the degrees of roughness, breathiness and tension from the type I signal to the type IV signal (Table 3). Thus, there is a *continuum* between the deviation of vocal quality and the behavior of the spectrographic signal.

Higher values of degrees of roughness and breathiness in types III and IV signals in relation to type I and type II signals are justified by the fact that these two perceptual parameters are associated in general with an increase in the irregularity and noise components in the signal, respectively[11-16].

Breathiness is characterized in the spectrographic tracing by the presence of additional diffuse noise in the high frequency bands and decreased energy in all frequency bands of the tracing[2,11,17,18]. In physiological terms, breathiness is associated with a lower convexity of the free edge of the vocal folds, less time at the closed phase of glottic cycles, and a greater degree of separation between vocal processes[19,20]. Thus, the increase in the degree of breathiness in the signal is compatible with the description recommended for type III and IV signals, which involve the presence of diffuse noise at high frequencies, a decrease in energy below 4 KHz, and a predominance of noise over the harmonic structure[5,6].

Roughness is a parameter related to irregularity in the vibratory pattern of the vocal folds. In the spectrographic tracing, roughness is characterized by the presence of low amplitude harmonics[3,14,18,21], subharmonics[5,11,17,22], and the presence of noise in the lower frequency ranges[13,18]. Thus, the increase in the degree of roughness may be associated with the description of type III and IV signals, which includes the presence of noise between low frequencies and the presence of subharmonics for intervals greater than one second[5,6].

Regarding the phonatory tension parameter, there was a difference only in type IV signals in relation to types I, II and III. Experiments with excised larynges demonstrated that the considerable increase in subglottic pressure generates irregular vibration, bifurcation, rough emission, and effort[23]. On the other hand, certain levels of tension may cause an increase in vocal intensity and manifest acoustically by the presence of a rich series of harmonics in the entire frequency range of the spectrographic tracing[24]. Thus, it is possible to understand why only type IV signals presented a higher degree of vocal tension in relation to the other types of signals. Probably, the classification proposed by Titze[5] and Sprecher et al.[6] focused on the signal's aperiodicity characteristics, which more directly contemplates the roughness and breathiness components in the emission and not the degree of tension associated with vocal production. Consequently, within the proposed classification criteria, the degree of tension only differs in type IV signals as it causes a greater irregularity and bifurcation in these signals.

In the present study, few signals were classified as type I, even among those without deviation in vocal quality. It should be noted that all individuals who participated in the study had vocal complaints, which may reflect on the decrease in vocal performance and/or changes in laryngeal functioning, which in turn may be related to laryngeal diagnosis and the intensity of vocal deviation[25]. Thus, although there is no direct and linear relation between the presence of vocal complaints reported by the patient and the deviation in vocal quality perceived audibly by the clinician[26,27], individuals with vocal complaints probably have slight changes in the vocal signal, which can be identified in the spectrographic tracing.

Add to this the fact that, in Titze's[5] classification, the type I signal must present a series of harmonics defined up to 4 KHz, regularity in tracing, absence of noise, and subharmonics. Such findings can be found more frequently in individuals with vocal training, which does not correspond to the sample of this study. On the other hand, in the analysis of mean and SD of the intensity of the vocal deviation of signals classified as type I, the values were compatible with a mild quality deviation of voice (41.42±10.33). This data reinforces that even signals that were evaluated as slightly deviated in the auditory-perceptual analysis can present a regular spectrographic tracing with a rich series of harmonics. Taken together, this information reinforces that the manifestation of a voice disorder is multidimensional, and that information of different natures is complementary in the evaluation process, especially with regard to the diagnostic confirmation of this disorder[1,3].

Most voices with deviation were classified as type II and type III. When analyzing the mean and SD values of the intensity of the vocal deviation in these signals, type II signals presented a mild degree deviation (44.77 ± 9.83), while type III tracing showed a moderate deviation degree (56.28±15.04). In addition, only signals with higher values of general grade (81.41±14.28) were classified as type IV. Therefore, such findings indicate that the classification proposed by Titze[5] and Sprecher et al.[6] may be useful as a measurement of treatment results since the classification reflects the intensity of the deviation and the presence of laryngeal alterations.

Thus, the findings of the present study using the spectrographic classification of the vocal signal proposed by Titze[5] and Sprecher et al.[6] may indicate that such classification can be used in evaluation reports mainly as a measurement of results of the treatments offered to the patient. However, some considerations must be made in relation to the results found.

First, the study sample consisted only of patients with voice disorders, which necessarily included a vocal complaint associated or not with the existence of laryngeal alterations and/or deviation in vocal quality. Thus, a control group with vocally healthy individuals was not formed, which makes it impossible to transfer the results for diagnostic confirmation procedures. The choice for the population investigated in this research was purposeful, since it aimed to understand whether the classification of the type of vocal signal was useful to characterize individuals with voice disorders and whether such typology was associated with the results of the laryngeal visual examination and the perceptual-auditory analysis. In clinical terms, the initial motivation for conducting this research was to understand whether this classification could be useful for the purpose of monitoring patients with voice disorders who undergo an intervention procedure (clinical or surgical), facilitating communication between professionals involved with vocal care.

Future studies should be carried out comparing individuals who are vocally healthy and those with voice disorders to verify whether the typology proposed for the classification of vocal signals is able to discriminate the mentioned populations. Such studies could elucidate whether this classification could be used for the purpose of diagnostic confirmation.

Finally, it should be considered that patients with different laryngeal diagnoses were included in this study, which increases the external validity of the findings and the possibility of generalization to patients with voice disorders in general. However, it does not allow understanding the behavior of the signals in function of the specificity of the diagnosed laryngeal lesion, which can be investigated in future studies.

In general, the results of this research may support the use of the classification of vocal signals proposed by Titze[5] and Sprecher et al.[6] as a measurement of results of treatments offered to patients with voice disorders since there is an association of the typology of signals with the presence of laryngeal alterations and auditory-perceptual data. However, one must always consider that the manifestation of a voice disorder is multidimensional and that the investigation and integration of information of different natures is recommended to characterize this disorder.

CONCLUSION

There is an association between the presence of laryngeal alteration, auditory-perceptual analysis of vocal quality, and the spectrographic classification of the vocal signal in individuals with voice disorders. Vocal signals of individuals without laryngeal disorders are predominantly classified as type I and type II, while vocal signals of individuals with laryngeal disorders are classified as types III and IV.

REFERENCES

1. Dejonckere PH, Bradley P, Clemente P, Cornut G, Crevier-Buchman L, Friedrich G, et al. A basic protocol for functional assessment of voice pathology, especially for investigating the efficacy of (phonosurgical) treatments and evaluating nem assessment techniques. Eur Arch Otorhinolaryngol. 2001;258(2):77-82. http://dx.doi.org/10.1007/s004050000299. PMid:11307610.
2. Lopes LW, Alves GAS, Melo ML. Content evidence of a spectrographic analysis protocol. Rev CEFAC. 2017;19(4):510-28. http://dx.doi.org/10.1590/1982-021620171942917.
3. Beber BC, Cielo CA. Features of wide and narrow band spectrography as for vocal emission of men with larynx without diseases. Rev CEFAC. 2012;14(2):290-7. http://dx.doi.org/10.1590/S1516-18462012005000008.
4. Yanagihara N. Significance of harmonic changes and noise components in hoarseness. JSHR. 1967;10(3):531-41. http://dx.doi.org/10.1044/jshr.1003.531. PMid:6081935.
5. Titze IR. Workshop on acoustic voice analysis: summary statement. Iowa: National Center for Voice and Speech; 1995. Technical report.
6. Sprecher A, Olszewski A, Jiang JJ, Zhang Y. Updating signal typing in voice: addition of type 4 signals. J Acoust Soc Am. 2010;127(6):3710-6. http://dx.doi.org/10.1121/1.3397477. PMid:20550269.
7. Brockmann-Bauser M, Bohlender JE, Mehta DD. Acoustic perturbation measures improve with increasing vocal intensity in individuals with and without voice disorders. J Voice. 2018 Mar;32(2):162-8. PMid:28528786.
8. Kempster GB, Gerratt BR, Verdolini Abbott K, Barkmeier-Kraemer J, Hillman RE. Consensus auditory-perceptual evaluation of voice: development of a standardized clinical protocol. Am J Speech Lang Pathol. 2009;18(2):124-32. http://dx.doi.org/10.1044/1058-0360(2008/08-0017). PMid:18930908.
9. Yamasaki R, Madazio G, Leão SHS, Padovani M, Azevedo R, Behlau M. Auditory-perceptual evaluation of normal and dysphonic voices using the voice deviation scale. J Voice. 2017;31(1):67-71. http://dx.doi.org/10.1016/j.jvoice.2016.01.004. PMid:26873420.
10. Kent RD, Read C. The acoustic analysis of speech. 2nd ed. San Diego: Singular Publishing Group; 2007.
11. D'Avila H, Cielo CA, Siqueira MA. Efeitos da técnica fonoterapêutica de fricativo sonoro /Z/ na voz: análise de um caso. Soc Bras Fonoaudiol. 2005;10(4):232-5.
12. McAllister A, Sederholm E, Sundberg J. Perceptual and acoustic analysis of vocal registers in 10-year-old children. Logoped Phoniatr Vocol. 2000;25(2):63-71. http://dx.doi.org/10.1080/14015430050175914. PMid:10955314.
13. Pontes PAL, Vieira VP, Gonçalves MIR, Pontes AAL. Características das vozes roucas, ásperas e normais: análise acústica espectrográfica comparativa. Rev Bras Otorrinolaringol. 2002;68(2):182-8. http://dx.doi.org/10.1590/S0034-72992002000200005.
14. Jotz GP, Cervantes O, Settani FAP, Angelis EC. Acoustic measures for the detection of hoarseness in children. Int Arch Otorhinolaryngol. 2006;10(1):14-20.
15. Lopes LW, Freitas JA, Almeida AA, Silva POC, Alves GAS. Performance of the phonatory deviation diagram in the evaluation of rough and breathy synthesized voices. Rev Bras Otorrinolaringol. 2018;84(4):460-72. http://dx.doi.org/10.1016/j.bjorl.2017.05.012. PMid:28732642.
16. Valentim AF, Côrtes MG, Gama AC. Análise espectrográfica da voz: efeito do treinamento visual na confiabilidade da avaliação. Rev Soc Bras Fonoaudiol. 2010;15(3):335-42. http://dx.doi.org/10.1590/S1516-80342010000300005.
17. Cielo CA, Ribeiro VV, Bastilha GR, Schilling NO. Quality of life in voice, perceptual-auditory assessment and voice acoustic analysis of teachers with vocal complaints. Audiol Commun Res. 2015;20(2):130-40. http://dx.doi.org/10.1590/S2317-64312015000200001511.
18. Lucero JC, Koenig LL. Simulations of temporal patterns of oral airflow in men and women using two-mass model of the vocal flods under dynamic control. J Acoust Soc Am. 2005;117(3 Pt 1):1362-72. http://dx.doi.org/10.1121/1.1853235. PMid:15807024.
19. Samlan RA, Story BH, Bunton K. Relation of perceived breathiness to laryngeal kinematics and acoustic measures based on computacional modeling. J Speech Lang Hear Res. 2013;56(4):1209-23. http://dx.doi.org/10.1044/1092-4388(2012/12-0194). PMid:23785184.
20. Narasimhan SV, Vishal K. Spectral measures of hoarseness in persons with hyperfunctional voice disorder. J Voice. 2017;31(1):57-61. http://dx.doi.org/10.1016/j.jvoice.2016.03.005. PMid:27080591.
21. Rodríguez-Parra MJ, Adrián JA, Casado JC. Comparing voice-therapy and vocal-hygiene treatments in dysphonia using a limited multidimensional evaluation protocol. J Commun Disord. 2011;44(6):615-30. http://dx.doi.org/10.1016/j.jcomdis.2011.07.003. PMid:21880326.
22. Jiang JJ, Zhang Y, Ford CN. Nonlinear dynamics of phonations in excised larynx experiments. J Acoust Soc Am. 2003;114(4 Pt 1):2198. http://dx.doi.org/10.1121/1.1610462. PMid:14587617.
23. Rees CJ, Blalock PD, Kemp SE, Halum SL, Koufman JA. Differentiation of adductor-type spasmodic dysphonia from muscle tension dysphonia by spectral analysis. Otolaryngol Head Neck Surg. 2007;137(4):576-81. http://dx.doi.org/10.1016/j.otohns.2007.03.040. PMid:17903573.
24. Verdolini K, Ramig LO. Review: occupational risks for voice problems. Logoped Phoniatr Vocol. 2001;26(1):37-46. http://dx.doi.org/10.1080/14015430119969. PMid:11432413.
25. Coyle SM, Weinrich BD, Stemple JC. Shifts in relative prevalence of laryngeal pathology in a treatment-seeking population. J Voice. 2001;15(3):424-40. http://dx.doi.org/10.1016/S0892-1997(01)00043-1. PMid:11575638.

26. Cohen SM, Pitman MJ, Noordzij JP, Courey M. Management of dysphonic patients by otolaryngologists. Otolaryngol Head Neck Surg. 2012;147(2):289-94. http://dx.doi.org/10.1177/0194599812440780. PMid:22368039.

27. Lopes LW, Silva HF, Evangelista DS, Silva JD, Simões LB, Silva POC, et al. Relationship between vocal symptoms, severity of voice disorders, and laryngeal diagnosis in patients with voice disorders. CoDAS. 2016;28(4):439-45. http://dx.doi.org/10.1590/2317-1782/20162015062. PMid:27356190.