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Original articles

# Content evidence of a spectrographic analysis protocol

## *Evidência de conteúdo de um protocolo de análise espectrográfica*

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**ABSTRACT**

**Objective:** to verify the content evidence of a spectrographic analysis protocol.

**Methods:** a methodological study in which five speech therapists who assessed the clarity and the relevance of the protocol were selected. The Content Validity Index (CVI) was used to investigate the level of agreement among judges regarding overall aspects, items and domains of the protocol.

**Results:** most judges considered the overall aspects of the protocol as comprehensive. As for clarity, 17 items showed an excellent content validity (CVI ≥ 0.78), three showed a good content validity (0.60 ≤ CVI ≤ 0.77) and two items were judged as poor (CVI ≤ 0.59). As for relevance, 19 items obtained an excellent content validity (CVI ≥ 0.78) and three had a good content validity (0.60 ≤ CVI ≤ 0.77). The judges suggested adding items related to vocal signal normality in all domains. After the analysis, 18 items required no reformulation, five items were added, three were reformulated and one was excluded.

**Conclusion:** the proposed protocol was regarded as a comprehensive one. The items presented a good to excellent content validity as for clarity and relevance. After this validation step, the protocol ended up presenting 25 items distributed into five domains.

**Keywords:** Validation Studies; Voice; Voice Disorders; Sound Spectrography; Speech, Language and Hearing Sciences

**RESUMO**

**Objetivo:** verificar a evidência de conteúdo de um protocolo de análise espectrográfica.

**Métodos:** trata-se de um estudo metodológico. Foram selecionados cinco fonoaudiólogos que avaliaram a clareza e relevância do protocolo. Utilizou-se o Índice de Validade de Conteúdo (IVC) para investigar o nível de concordância entre os juízes quanto ao aspecto global, itens e domínios do protocolo.

**Resultados:** a maioria dos juízes considerou o aspecto global do protocolo abrangente. Quanto à clareza, 17 itens demonstraram validade de conteúdo excelente (IVC≥ 0,78), três obtiveram boa validade de conteúdo (0,60 ≤ IVC≤ 0,77) e dois itens foram julgados como ruins (IVC≤ 0,59). Com relação à relevância, 19 itens obtiveram excelente validade de conteúdo (IVC≥ 0,78) e três foram avaliados com boa validade de conteúdo (0,60 ≤ IVC≤ 0,77). Os juízes sugeriram a inserção de itens relativos à normalidade do sinal vocal em todos os domínios. Após análise, 18 itens mantiveram-se sem reformulação, cinco itens foram inseridos, três itens foram reformulados e um item foi excluído.

**Conclusão:** o protocolo proposto foi considerado abrangente. Os itens apresentaram validade de conteúdo de boa a excelente quanto à clareza e relevância. Após essa etapa de validação, o protocolo passou a apresentar 25 itens, distribuídos entre os cinco domínios.

**Descritores:** Estudos de Validação; Voz; Distúrbios da Voz; Espectrografia do Som; Fonoaudiologia

## INTRODUCTION

Acoustic analysis is one of the most mentioned and used methods in clinical and research contexts for the evaluation of vocal emission. It provides an integrated understanding of the relationship between vocal *input* and *output*, algorithms with a high reproducibility, quantification of deviations in signals, and allows a comparison with normative data[1].

In general, the method of acoustic analysis may include the extraction of measurements that quantify some properties of vocal signals and/or provides a qualitative description of that visual patterns of such signals[2].

One of the advantages of acoustic analysis based on extraction of measurements is the possibility of generating quantitative data and comparing them with each other and with normative values related to different laryngeal conditions and different types of vocal quality deviation[1]. On the other hand, the measurements most commonly used in clinical vocal evaluation routines (*jitter* and *shimmer*), based on linear models of vocal production, have a limited reliability for the analysis of signals with a high degree of aperiodicity[3], such as type II, III and IV signals[4].

The use of spectrogram descriptive analysis, perceptual-auditory analyses and/or extraction of acoustic measurements based on non-linear models of vocal production are recommended when signals contain a great amount of noise and irregularity[4]. The first two procedures are more accessible and used in most specialized voice health services[1]. Non-linear analysis is not yet integrated with most marketed softwares among clinicians, and demands a longer signal processing time.

Descriptive acoustic analysis corresponds to descriptions of visual patterns of waveforms of vocal signals[2], energy spectrum, broadband (formants) or narrow-band spectrography[5], among others. The visual inspection of the acoustic behavior of a signal is a subjective method similar to perceptual-auditory evaluation. It is influenced by variables such as the evaluator's experience[6]. The main advantage of descriptive analysis is the possibility of a qualitative signal evaluation independent from the degree of aperiodicity and noise in the emission.

The spectrogram is the main feature used for descriptive analysis, and can be defined as a three-dimensional graph that records frequencies on the vertical axis, signal temporal characteristics in the horizontal axis, and amplitude of soundwave components by a color contrast in a curve design[5]. Narrow-band spectrography of sustained vowel is used in procedures for evaluating voice disorders[7] and professional voice[8]. Several studies[9-12] relate the characteristics of this type of spectrographic tracing to vocal quality deviation and changes in laryngeal functioning[11].

There are two classic descriptions[4,13] for the classification of vocal signals based on narrow-band spectrographic tracings used both in clinical routines and in research procedures.

Yanagihara[13] classifies the signals into types 1, 2, 3 and 4 depending on regularity of the harmonics, presence of noise in different frequency bands and relations between the harmonic structure and noise in tracing. The author sought to find a description of the main acoustic events related to auditory perception of vocal deviation intensity based on the assumption that the perception of intensity of deviation was directly related to quantity and distribution of the noise component and to the reduction in harmonics in the spectrogram.

The classification of Titze[4] is based on a nonlinear dynamics model of vocal production, and characterizes quantitative changes in signal behavior resulting from a change in the vibratory pattern of the vocal folds. It classifies the signals into type I, II and III, in a *continuum* that goes from "almost periodical" signal to absence of a periodicity structure in the tracing.

The classification of Yanagihara[13] is the most used in the clinical context to characterize an observed signal deviation and its relation with the intensity of vocal deviation in the perceptual-auditory plane. In turn, Titze's[4] classification is more commonly used in research procedures aiming to determine the type of analysis to be performed (linear *vs*. non-linear, standard visual analysis *vs*. measurement extraction).

None of these authors[4,13] aimed to develop a script for spectrographic analysis for different vocal conditions. Moreover, they do not provide descriptions of the behavior of harmonics and noise components over time (which is one of the dimensions of the spectrogram), an important aspect for the characterization of a deviated vocal signal. In addition, Yahagihara's classification model[13] does not address the spectrographic characterization of signals produced by individuals without vocal deviation.

Thus, it is observed that, in the scientific literature and in clinical routines of vocal evaluation, there is no standardized instrument containing descriptive terms

or items used to analyze spectrographic tracings. In every study[5,12], researchers list different descriptors for spectrograms and, in general, interpret them based on Yanagihara's[13] or Titze's[4] classifications. This makes it difficult to compare the results of different studies and hinders the communication between specialists in a clinical context[14]. In addition, Valentim, Côrtes and Gama[15] reinforce the importance of establishing a consensus regarding concepts and descriptions of narrow-band spectroscopy.

In clinical practice, the use of protocols evaluating specific aspects allows professionals to act in a planned way, document and share procedures properly, evaluate evolutions and make the analyses reproducible[14].

The proposal for a new instrument should ensure that interpretations of scores are valid in order to achieve the desired objective, and that they are reliable in relation to the consistency of items, reproducibility and control of measurement errors[16].

One of the steps in the process of designing an instrument is content evidence or validation stage, which investigates how an instrument represents the most relevant and important aspects of a concept in the context of application of a given measurement[16]. It is verified based on analyses by individuals with expertise in an area regarding the semantic understanding of the items that make up the instrument (clarity) and the relevance of such items[17].

Thus, considering the importance of narrow-band spectrographic analysis for the clinical context and the absence of a standardization of descriptors used to evaluate spectrographic graphs, the objective of this study is to verify the content evidence of a spectrographic analysis protocol.

The development of this instrument may assist clinicians in the evaluation and monitoring of voice disorders. It also contributes to the training of new evaluators, whether academic or professionals.

## METHODS

### Study design

This is a methodological research[18] because it is situated in the context of investigating, organizing and analyzing data to design, validate and evaluate the proposal of a spectrographic analysis instrument of vocal signals. This research was evaluated and approved by the Research Ethics Committee of the Federal University of Paraíba under opinion no. 508.200/2013.

### Sample

To select volunteers to participate in this research, the "*The Fehring Model*"[19] scoring system was adapted. This system was developed for the selection of experts for content validation in Nursing, and can be adapted for the selection of experts in other areas. From the scoring system presented by the model (Figure 1), specialists with a minimum score of five points should be selected.

| FEHRING CRITERIA | POINTS | ADAPTED CRITERIA | ADAPTED POINTS |
|---|---|---|---|
| Master in Nursing | 4 | Graduation in Speech-Language Therapy (compulsory criterion) | 0 |
| Master's degree in Nursing - dissertation with a relevant content within the clinical area | 1 | Master's dissertation on Voice | 2 |
| Research (published) in Diagnostics | 2 | Voice Research | 2 |
| Article published on Diagnostics in a reference journal | 2 | Article published on Voice in a ≥ B2 journal | 2 |
| PhD in Diagnosis | 2 | PhD thesis on Voice | 4 |
| Clinical practice of at least one year in Nursing in a medical clinic | 1 | Clinical practice of at least one year in Voice and experience with narrow-band spectrographic analysis | 2 |
| Certificate in clinical medicine with proven clinical practice | 2 | Voice Specialist | 2 |
| Maximum score | 14 | Maximum score | 14 |

**Figure 1.** Adaptation of the expert scoring system for Fehring content validation

Subsequently, *e-mails* were sent to nine Speech-Language experts working in the city where the survey was conducted. The list of these professionals was provided by the Coordination of the Speech-Therapy Course of the institution of origin of this research.

Of the nine professionals contacted, three did not reach the minimum score (≥5 points) and one was not available to participate in the survey. Thus, 5 speech therapists who met the eligibility criteria were selected, all of them teaching undergraduate speech therapy students. Considering that the visual inspection of the spectrographic tracing is subjective and therefore influenced by the evaluator's experience in using the instrument, one of the adopted criteria was experience in performing narrow-band spectrographic analyses (Figure 2). Although the criterion used in this research, based on the theoretical model used[19], recommended a minimum experience time of one year with spectrographic analysis, all judges who met the eligibility criteria had more than five years of clinical practice with voice-related issues using spectrographic tracing as a routine procedure.

The number of judges participating in this research is in accordance with the literature[20], which recommends a minimum of five and a maximum of ten specialists participating at this stage of the validation process.

After the confirmation of availability and the meeting of eligibility criteria, a new contact was made by *e-mail*, and a date was set for a meeting, which was conducted individually with each judge.

## Procedures

Considering the development stages of an evaluation instrument[17], this research is at the theoretical procedures stage, which is subdivided into elaboration of the constructs or dimensions to be evaluated by the instrument, design of the instrument and content validation. The methodological procedures will be described in function of such subdivisions.

## Elaboration of the construct

The design of the construct is related to the theoretical perspective that defines the object to be investigated by a particular instrument, including identification of the dimensionality of the construct, which refers to its semantic structure and to the understanding of its constitution as uni or multidimensional; constitutive definition, referring to the abstract conceptualization of the construct; and operational definition, which specifies the concrete representation of the concept[17].

This study has as its object narrow-band spectrography of sustained vowels in the context of clinical evaluation of voice disorders. In this case, the main question asked for the definition of dimensionality was: does the behavior of the signal of a vowel sustained in narrow-band spectroscopy is a single construct with a single possibility of manifestation, or must different components be distinguished to describe such behavior?

In order to answer this question and, consequently, define the dimensionality of the construct studied, an integrative literature review was conducted on narrow-band spectrographic analysis, including articles indexed in the databases *Medline* and *Pubmed*. The following descriptors were used for the search in databases: "*voice assessment and spectrography*", "*voice assessment and spectrogram*", "*voice disorder and spectrography*", "*voice disorder and spectrogram*", "*voice and spectrography*", and "*voice and spectrogram*".

Articles were selected according to the following eligibility criteria:

a) Presence of the descriptors cited in titles, abstracts or keywords;
b) Studies that had as research object narrow-band spectrographic analysis or that listed it among its methodological procedures;
c) Sample containing all age groups;
d) Articles in English, Portuguese or Spanish;
e) Full articles available in the databases from 1994 to 2014.

67 articles were found. 35 articles were excluded because they did not meet the eligibility criteria, remaining 32 articles. The analysis of these articles was guided by the research question previously mentioned, seeking to identify the main descriptors for vocal signal behavior of a vowel sustained in the spectrographic narrow-band tracing.

After reading all the material, 44 descriptors were used to characterize the signal behavior in the narrow-band spectrogram. A reanalysis of this list of descriptors was carried out, seeking to exclude terms that described the same characteristic of the tracing, resulting in 22 descriptors[21].

Thus, from the integrative literature review and the terms found to characterize vocal signal behavior in a narrow-band spectrographic graph, we identified

the multidimensionality of the studied construct. Five dimensions were listed considering temporal characteristics of emission, distribution of energy and noise in function of frequency bands, and morphological description of harmonics. Figure 2 shows the concept adopted for the construct studied, construct dimensions and its respective constitutive and operational definitions.

These five dimensions elucidate the behavior of vocal signals in the spectrographic graph taking into account its three-dimensionality (time domain, frequency range and signal amplitude) and the main components mentioned in the literature regarding deviant voices. The temporal aspect was listed in two domains ("onset of emission" and "temporal aspects of emission") since there are particularities at the onset of vocal emission which present relevant clinical implications and specific and well-defined physiological and perceptual correlates[22].

In general, evaluation protocols can be organized into domains and items. Domains are an operation of classification of elements of a message following certain criteria, facilitating the analysis of information and contributing significantly to explain it[17]. Items are specific descriptions that comprise a domain. Throughout this work, the word "domain" will be used to refer to the construct dimensions. Such use is justified because this term is most commonly used for valuation tools in a research area. Its function is to group items that have an interrelationship and represent a certain dimension of the proposed instrument.

## Development of the instrument

After the adoption of concepts related to the construct, the determination of its dimensionality and respective constitutive and operational definitions, the construction of the items began (construct operationalization). This corresponds to the development of tasks future users of the instrument should execute to evaluate the construct and its dimensions[17].

Considering that the items should be selected according to the operational definitions of the construct, we chosen in this step to review established operational definitions (Figure 2) and rephrase them semantically to establish the items of the spectrographic analysis protocol.

At this stage, the criteria of Pasquali[17] were used for the construction and selection of the number of items. In general, it is suggested that the initial version of an instrument present more than 20 items for the representation of the construct[17]. Thus, 22 items were proposed for the initial version of the spectrographic analysis protocol (Figure 3).

The stages of elaboration of the construct and the development of the instrument were carried out and published in a previous work[21]. They are described here to subsidize the understanding of the content validation stage, which is the objective of this research.

## Content validation

After the operationalization of the construct into items to define the spectrographic analysis protocol, the validation, or evidence, stage of the content of these items began. This stage seeks to determine the adequacy of an item as a concrete representation of the construct under study[17]. Studies focusing on content validity involve an analysis of understanding, or clarity, of items (semantic analysis), and the analysis of the pertinence, or relevance, of such items (analysis by judges).

At this stage of the study, five speech therapists participated. They had expertise in vocal assessment and experience in using narrow-band spectrographic analysis, according to the eligibility criteria previously defined. The judges individually assessed the proposed instrument in a single session, according to availability of schedule. The session lasted an average of 90 minutes. At the session, only the judge and one of the researchers involved in the research were present.

At the beginning of the collection, each judge was informed about the research objectives and signed an informed consent. Then, the initial version of the spectrographic analysis protocol was presented to each judge, providing them with a printed copy of the protocol and explaining how the elaboration of this version occurred.

The judges received the analysis form of the semantic and relevance analysis of the items. They were oriented about the analysis of clarity, which referred to the writing of the items, evaluating whether the semantic aspect propitiated the understanding of the construct and adequately expressed what it was proposed to measure, whether they were written in such a way that the concept was understandable, and adequately expressed what was expected to be measured[17], and item relevance analysis, which investigates whether the items were really relevant to represent the behavior of the construct studied and to achieve the proposed objectives during the use of the instrument[17].

| ADOPTED CONCEPT | DIMENSIONALITY AND CONSTITUTIVE DEFINITION | OPERATIONAL DEFINITION |
|---|---|---|
| The narrow-band spectrogram of vocal signals corresponds to a three-dimensional graph representing the sound spectrum of the frequencies (vertical dimension) of signals, its evolution in function of time (horizontal dimension), and amplitude of frequencies (color contrast) generated using Fourier analyses and narrow-band filters. The narrow-band spectrography shows the behavior of harmonics and noise in emission in function of time and frequency bands. In clinical terms, it represents the emission produced by the glottal source amplified/modified by the vocal tract. | Onset of emission: characterizes the behavior of the signal at the onset of vocal emission, corresponding, in the perceptive-auditory plane, to the evaluation of the vocal attack and, in the physiological plane, to the glottic configuration and speed of adduction of vocals folds (WATSON, BAKEN e ROARK, 2016). | Noise at the onset of emission (ROARK et al., 2012). |
| | | Dark vertical striations defined at the onset of emission (ANDRADE, 1999). |
| | | Energy above 5,000 Hz at the onset of emission (DRUMOND AND GAMA, 2006). |
| | Temporal aspects of emission: related to the behavior of vocal signals in the spectrographic tracing over time (BEHLAU, 2001). It allows understanding energy variation, and noise and morphological aspects of harmonics along a vocal emission (ANDRADE, 2003; LEÃO, 2008; CARRASCO, OLIVEIRA and BEHLAU, 2010). Concerning the perceptual-auditory correlate, the temporal aspect is related to a tense vocal quality and instability/fluctuations of the signal along the emission. Physiologically, this dimension is related to the maintenance of the closed phase of glottic cycles and to the vibratory periodicity of vocal folds (Vieira et al., 2006). | Irregular tracing (BEBER and CIELO, 2011). |
| | | Gradual loss of harmonics in the tracing over time (CIELO, ROMAN-NIEHUES, CHRISTMANN, 2013). |
| | | Abrupt tracing interruptions (REES et al., 2007). |
| | Distribution of energy (of harmonics) in the tracing: describes the overall behavior of sound energy (harmonics) in the tracing in function of frequency bands (vertical dimension). In the perceptual plane, it is related to the vocal quality of the breath, loudness and resonance, whereas in the physiological plane, it corresponds to the modulation of airflow in the glottis and amplification/modification of the sound by resonators (larynx, pharynx, oral and nasal cavities). | Light harmonics or weak degree of darkening (CIELO et al., 2015). |
| | | Low energy and number of harmonics above 4,000 Hz (BARRICHELO et al., 2001). |
| | | Formation of harmonics above 4,000 Hz (BARRICHELO, 2001). |
| | | Decreased energy or number of harmonics up to 4,000 Hz (CIELO, ROMAN-NIEHUES, CHRISTMANN, 2013). |
| | | Increase of energy between 1,000-3,000 Hz (HANAYAMA, TSUJI, PINHO, 2004). |
| | | Predominance of the tracing of F0 in detriment of other harmonics (NARASIMHAN and VISHAL, 2016). |
| | | Reduced energy level over the entire frequency range along the tracing (VALENTIM, CÔRTES and GAMA, 2011). |
| | | Increased energy level over the entire frequency band along the tracing (VIEIRA, BIASE, PONTES, 2006). |
| | Description of harmonics (structure of harmonics): refers to the description of the structure/morphology of harmonics present in the spectrographic tracing. In the perceptive-auditory plane, it is related to a rough and/or breathy vocal quality. In physiological terms, it corresponds to the maintenance of the closed phase of glottic cycles, amplitude and regularity of vocal fold mucosal vibration. | Irregular horizontal striations between the harmonics (YANAGIHARA, 1967). |
| | | Indefinite harmonics or sketch of harmonics (CIELO, RIBEIRO and BASTILHA, 2015). |
| | | Low amplitude harmonics (BEBER, CIELO, 2011). |
| | | Irregular harmonics (BEBER, CIELO, 2011) |
| | Noise distribution in the tracing: characterization of the presence and the behavior of noise in the spectrographic tracing. The perceptual-auditory correlate of this domain is the rough and/or breathy vocal quality and intensity of vocal deviation. In physiological terms, it corresponds to the maintenance of the closed phase of glottic cycles, amplitude and regularity of vocal fold mucosal vibration. | Noise among harmonics below 4,000 Hz (RODRÍGUEZ-PARRA et al., 2011). |
| | | Noise above 4,000 Hz (NEMR et al., 2013). |
| | | Diffuse additional noise above 4,000 Hz (CIELO, RIBEIRO and BASTILHA, 2015). |
| | | Noise in the tracing throughout the vocal emission (ORTIZ and CARRILLO, 2008). |

**Figure 2.** Adopted concept, dimensionality, constitutive definition and operational definition of the construct "vocal signal behavior in narrow-band spectrography".

1) Onset of emission

| | | Item |
|---|---|---|
| a) | ( ) | Presence of noise at the onset of emission |
| b) | ( ) | Dark vertical striations at the onset of emission |
| c) | ( ) | Onset of emission with energy above 5,000 Hz |

2) Temporal aspects of emission

| | | Item |
|---|---|---|
| d) | ( ) | Presence of tracing irregularity |
| e) | ( ) | Gradual definition/tracing loss |
| f) | ( ) | Presence of abrupt tracing interruptions |

3) Distribution of energy in the tracing

| | | Item |
|---|---|---|
| g) | ( ) | Presence of light harmonics or with a weak darkening |
| h) | ( ) | Decreased energy and number of harmonics above 4,000 Hz |
| i) | ( ) | Presence of harmonics above 4,000 Hz |
| j) | ( ) | Decreased energy or reduced number of harmonics up to 4,000 Hz |
| k) | ( ) | Energy increase between 1,000-3,000 Hz |
| l) | ( ) | Predominance of the tracing of F0 in detriment of other harmonics |
| m) | ( ) | Decreased energy level over the entire frequency range along the tracing |
| n) | ( ) | Increased energy level over the entire frequency band along the tracing |

4) Description of harmonics

| | | Item |
|---|---|---|
| o) | ( ) | Presence of irregular horizontal striations between harmonics |
| p) | ( ) | Presence of undefined harmonics or harmonic sketches |
| q) | ( ) | Presence of low amplitude harmonics |
| r) | ( ) | Presence of irregular harmonics |

5) Distribution of noise in the tracing

| | | Item |
|---|---|---|
| s) | ( ) | Presence of noise between harmonics below 4,000 Hz |
| t) | ( ) | Presence of noise between harmonics above 4,000 Hz |
| u) | ( ) | Presence of additional diffused noise above 4,000 Hz |
| v) | ( ) | Presence of noise in the tracing throughout the vocal emission |

**Figure 3.** Initial version of the Spectrographic Analysis Protocol

As for clarity, judges should mark on the form whether the item was considered "unclear" (1), "little clear, needing a reformulation" (2), "clear" (3) or "very clear" (4). As for relevance, items could be evaluated as "not relevant" (1), "needs a review to be relevant" (2), "relevant" (3) or "very relevant" (4). If the evaluators marked the last two options of clarity and relevance, they should proceed writing a justification for both. The answers regarding clarity and relevance received scores ranging from 1 to 4[23] for further analysis.

Throughout the application session of the evaluation form, a presentation of slides in PowerPoint containing narrow-band spectrograms was presented to the judges, exemplifying each item defined in the protocol. Judges could consult this material at any time during the session if they so wished.

The spectrograms used in this presentation were generated in the software *Fonoview* using a sampling rate of 44,000 Hz, windowing of 40 ms, update time of 2.5 ms, dynamic amplitude range of 60 dB, frequency limit of 7,500 Hz, and minimum time interval of 3 s. The sustained vowel /ɛ/ of patients attended in the same laboratory where this research was performed was used as sample. All the samples were part of a database and did not have to be exclusively collected for this study.

From the items of the initial version of the protocol and two concepts underlying each of them, two of the researchers of this study selected three examples of spectrographic tracings that addressed each item of the protocol, totaling 66 spectrograms. The main criterion for the selection of these spectrograms was the consensus among judges regarding the image of the tracing and the item evaluated. Next, the spectrograms were saved in image format (.jpeg) and placed into a Powerpoint slide, as shown in Figure 4. The specific aspect addressed in the item was highlighted with a blue arrow. The title of the slide highlighted the domain evaluated and, above the tracing, there was a table highlighting in red the item evaluated (Figure 4).

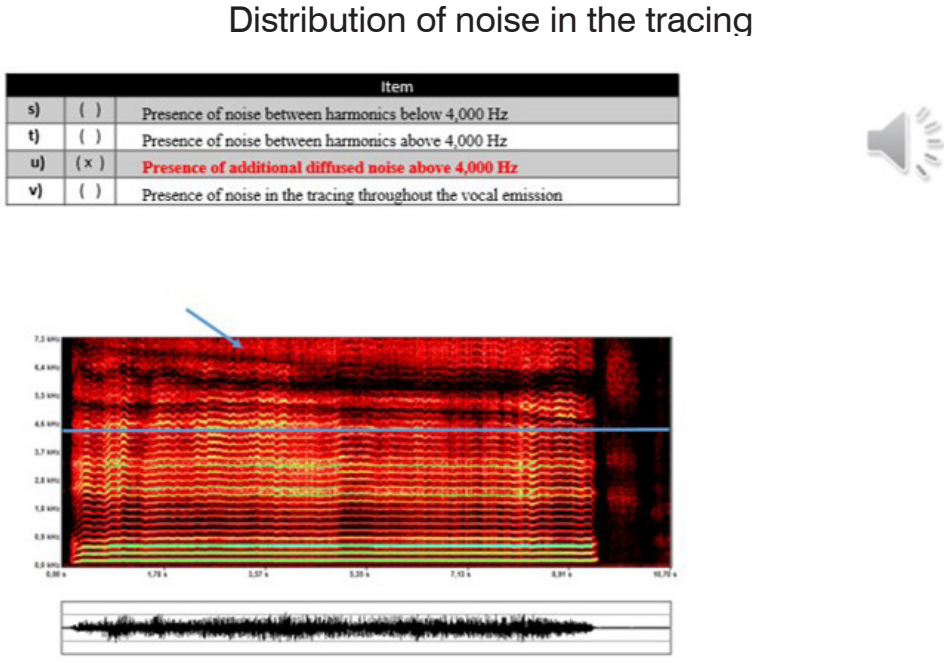


**Figure 4.** Illustration of a PowerPoint screen for the vowel /ɛ/ in the narrow-band spectrographic graph available to the judges for consultation during the evaluation session. The blue arrow highlights the item shown by this spectrogram, referring to "additional diffuse noise at frequencies above 4 KHz".

## Data analysis

For the analysis of clarity and relevance of items, the calculation of the Content Validity Index (CVI), total (CVI-T) and individual (CVI-I), was performed. The CVI is a commonly used method in studies aiming to evaluate the content validity of a construct[24], since it evaluates the percentage of judges who are in agreement on the aspect evaluated by the instrument[18]. It allows both an analysis of each item individually and an analysis of the instrument as a whole.

To calculate the CVI-I, the evaluators' scores as for clarity and relevance of items were taken into account. They varied from 1 to 4, as previously described. The CVI-I was calculated using the following formula[24]:

$$\text{CVI-I} = \frac{\text{number of answers “3” or “4”}}{\text{total number of answers}}$$

The CVI-T was calculated using a simple mean of all CVI-I obtained for items regarding clarity and relevance, respectively. In this study, we used the following classification[18] for the interpretation of CVI values: excellent (CVI $\geq$ 0.78), good (0.60 $\geq$ CVI $\leq$ 0.77) and poor (CVI $\leq$ 0.59). The items that obtained a value lower than 0.60 for clarity or relevance were obligatorily reformulated or excluded from the protocol.

## RESULTS

As for clarity and relevance, CVI-T values were 0.80 and 0.90, respectively (Tables 1 and 2), both considered excellent according to the classification used.

In the individual evaluation of items (CVI-I) as for clarity, 17 items presented an excellent evaluation, three items had a good evaluation and two items were considered poor (Table 1).

Regarding the individual evaluation of items (CVI-I) as for relevance, 19 items had an excellent evaluation and three items were judged as good (Table 2).

## DISCUSSION

The visual evaluation of the spectrographic tracing includes the analysis of distribution and characterization of harmonics and noise in function of time and frequency band of the tracing. The objective of this research is to verify the content evidence of a spectrographic analysis protocol considering that it must be comprehensive enough to contemplate temporal and frequency aspects of harmonics and noise in tracings, making the characterization of vocal deviation possible. In addition, the items that comprise such an instrument should be clear and relevant for a clinical application to assess vocal deviations.

Next, we will discuss the results of the first validation phase of the spectrographic analysis protocol, which corresponds to the verification of content evidence, including clarity and relevance of items within their respective domain.

### Evaluation of clarity and relevance of items of the spectrographic analysis protocol

In general, the items in the protocol were judged as excellent as for clarity and relevance. This result may indicate that the items are clear to evaluators, who will be the population to which the instrument is intended, making the concept understandable[25] and not hindering evaluations when using the protocol. It is relevant because it is able to reflect pre-defined concepts for the protocol[24], reaching the proposed objective, which is to evaluate signal behavior of a sustained vowel by narrow-band spectrography.

To facilitate the interpretation of results regarding the clarity and relevance of items of the protocol, we decided to analyze them separately based on domains.

### “Onset of emission” domain

This domain was created to group items that characterized the behavior of the signal at the onset of vocal emission, corresponding, in the perceptive-auditory plane, to the evaluation of vocal attack and, in the physiological plane, to glottic configuration and speed of adduction of vocals folds at the onset of phonation[22]. The onset of emission is an important aspect for vocal evaluation and is associated to vocal health, efficiency and quality issues[22].

The onset of phonation includes a “pre-phonatory” adjustment phase associated with the establishment of tension, aerodynamic force and adduction of vocal folds appropriate to emission. The “attack” phase is associated with the onset of vocal fold vibration and sound production[22]. Changes in this process cause visible changes in the spectrographic graph, such as the presence of noise at the onset of emission. From the onset of emission, it is possible to observe laryngeal hypofunctional conditions by means of breathy vocal attacks, or hyper-functional laryngeal conditions by means of abrupt vocal attacks[26].

**Table 1.** Judges' assessment as for the clarity of the items of the Spectrographic Analysis Protocol

| Items | Assessment of item clarity | | | | Total | CVI-I |
|---|---|---|---|---|---|---|
| | Not clear | Little clear, needing reformulation | Clear | Very clear | | |
| Presence of noise at the onset of emission | 0 | 0 | 2 | 3 | 5 | 1 |
| Dark vertical striations defined at the onset of emission | 0 | 1 | 2 | 2 | 5 | 0.80 |
| Onset of emission with energy above 5,000 Hz | 1 | 3 | 0 | 1 | 5 | 0.20 |
| Presence of tracing irregularity | 0 | 0 | 2 | 3 | 5 | 1 |
| Gradual definition/tracing loss | 0 | 1 | 2 | 2 | 5 | 0.80 |
| Presence of abrupt tracing interruptions | 1 | 2 | 0 | 2 | 5 | 0.40 |
| Presence of light harmonics or with a weak darkening | 1 | 1 | 2 | 1 | 5 | 0.60 |
| Decreased energy and number of harmonics above 4,000 Hz | 0 | 1 | 1 | 3 | 5 | 0.80 |
| Presence of harmonics above 4,000 Hz | 0 | 1 | 0 | 4 | 5 | 0.80 |
| Decreased energy or reduced number of harmonics up to 4,000 Hz | 0 | 2 | 1 | 2 | 5 | 0.60 |
| Energy increase between 1,000-3,000 Hz | 0 | 0 | 1 | 4 | 5 | 1 |
| Predominance of the tracing of F0 in detriment of other harmonics | 0 | 0 | 0 | 5 | 5 | 1 |
| Decreased energy level over the entire frequency range along the tracing | 0 | 0 | 1 | 4 | 5 | 1 |
| Increased energy level over the entire frequency band along the tracing | 0 | 1 | 0 | 4 | 5 | 0.80 |
| Presence of irregular horizontal striations between harmonics | 0 | 0 | 2 | 3 | 5 | 1 |
| Presence of undefined harmonics or harmonic sketches | 0 | 1 | 1 | 3 | 5 | 0.80 |
| Presence of low amplitude harmonics | 0 | 2 | 1 | 2 | 5 | 0.60 |
| Presence of irregular harmonics | 0 | 1 | 1 | 3 | 5 | 0.80 |
| Presence of noise between harmonics below 4,000 Hz | 0 | 0 | 0 | 5 | 5 | 1 |
| Presence of noise between harmonics above 4,000 Hz | 0 | 0 | 0 | 5 | 5 | 1 |
| Presence of additional diffused noise above 4,000 Hz | 0 | 1 | 3 | 1 | 5 | 0.80 |
| Presence of noise in the tracing throughout the vocal emission | 0 | 0 | 1 | 4 | 5 | 1 |
| Total | 3 | 18 | 23 | 66 | 110 | 0.80 |

**Subtitle**: CVI-I= Content Validity Index individual

**Table 2.** Judges' assessment as for the relevance of the items of the Spectrographic Analysis Protocol

| Items | Evaluation of item relevance | | | | Total | CVI-I |
|---|---|---|---|---|---|---|
| | Not relevant | Needs a review to be relevant | Relevant | Very relevant | | |
| Presence of noise at the onset of emission | 0 | 0 | 0 | 5 | 5 | 1 |
| Dark vertical striations defined at the onset of emission | 0 | 0 | 0 | 5 | 5 | 1 |
| Onset of emission with energy above 5,000 Hz | 0 | 1 | 2 | 2 | 5 | 0.80 |
| Presence of tracing irregularity | 0 | 0 | 1 | 4 | 5 | 1 |
| Gradual definition/tracing loss | 0 | 0 | 3 | 2 | 5 | 1 |
| Presence of abrupt tracing interruptions | 1 | 1 | 1 | 2 | 5 | 0.60 |
| Presence of light harmonics or with a weak darkening | 0 | 0 | 2 | 3 | 5 | 1 |
| Decreased energy and number of harmonics above 4,000 Hz | 0 | 1 | 1 | 3 | 5 | 0.80 |
| Presence of harmonics above 4,000 Hz | 0 | 1 | 0 | 4 | 5 | 0.80 |
| Decreased energy or reduced number of harmonics up to 4,000 Hz | 0 | 0 | 2 | 3 | 5 | 1 |
| Energy increase between 1,000-3,000 Hz | 0 | 0 | 2 | 3 | 5 | 1 |
| Predominance of the tracing of F0 in detriment of other harmonics | 0 | 0 | 2 | 3 | 5 | 1 |
| Decreased energy level over the entire frequency range along the tracing | 1 | 0 | 0 | 4 | 5 | 0.80 |
| Increased energy level over the entire frequency band along the tracing | 0 | 0 | 1 | 4 | 5 | 1 |
| Presence of irregular horizontal striations between harmonics | 0 | 0 | 1 | 4 | 5 | 1 |
| Presence of undefined harmonics or harmonic sketches | 0 | 0 | 1 | 4 | 5 | 1 |
| Presence of low amplitude harmonics | 0 | 0 | 1 | 4 | 5 | 1 |
| Presence of irregular harmonics | 1 | 1 | 0 | 3 | 5 | 0.60 |
| Presence of noise between harmonics below 4,000 Hz | 0 | 0 | 0 | 5 | 5 | 1 |
| Presence of noise between harmonics above 4,000 Hz | 0 | 0 | 0 | 5 | 5 | 1 |
| Presence of additional diffused noise above 4,000 Hz | 0 | 2 | 1 | 2 | 5 | 0.60 |
| Presence of noise in the tracing throughout the vocal emission | 0 | 0 | 0 | 5 | 5 | 1 |
| Total | 3 | 7 | 21 | 79 | 110 | 0.90 |

**Subtitle**: CVI-I= Content Validity Index individual

The domain "Onset of emission" contemplated three items. Of these, the items "**Presence of noise at the onset of emission**" and "**Presence of defined dark vertical striations at the onset of emission**" were evaluated as excellent for clarity and relevance. The item "**Onset of emission with energy above 5,000 Hz**" was judged as poor as for clarity and excellent as for relevance.

The item "**Presence of noise at the onset of emission**" corresponds to the auditory correlate of breathy vocal attack (with audible air escape at the onset of the sound) and, in the physiological plane, corresponds to the inefficiency of glottal closure[26].

The "**Presence of defined dark vertical striations at the onset of** emission" is related to the presence of a hard vocal attack, which is defined as one example

of vocal misuse[27] since there is a fast and complete adduction of vocal folds before the onset of phonation.

The onset of emission is a parameter commonly analyzed in clinical vocal assessment routines mainly regarding the type of vocal attack. This may justify the finding that the items "**Presence of noise at the onset of emission**" and "**Presence of defined dark vertical striations at the onset of emission**" were considered excellent both as for clarity and relevance, indicating that the semantic aspect of these items makes them comprehensible to the evaluator, and that they are important to characterize the behavior of the vocal signal in the narrow-band spectrography during vocal evaluation procedures.

The item "**Onset of emission with energy above 5,000 Hz**" was judged as poor as for clarity and excellent as for relevance. The increase in phonatory efforts at the onset of emission, due to a contraction of the laryngeal musculature, increases the resistance to airflow and the closed phase of glottic cycles, generating an increase in the energy of tracings at high frequencies due to an increase in sound pressure[28]. Such finding is common in mass lesions of vocal folds[29].

Thus, the item "**Onset of emission with energy above 5,000Hz"** was constructed precisely to contemplate cases in which there is an increase in energy at the first seconds of onset of emission, not necessarily restricted to vocal attacks.

With regard to the clarity of this item, the judges commented on the difficulty in understanding the word "energy", in addition to being considered by one of the judges as an item not characteristic only of the onset of emission. Therefore, considering the physiological and perceptual conditions underlying this item and the fact that judges evaluated it as excellent as for relevance, it is justified to keep the item since it is an important representation of the behavior of vocal signals.

Thus, the item was reformulated to "**Onset of emission with a high number of irregular harmonics**", since the energy increase causes an increase in the number of harmonics, and they are irregular due to an association with the increase in phonatory tension.

The judges suggested the inclusion of items describing the behavior of a normal vocal signal in each domain. Therefore, a new item entitled "**Onset of a tracing without irregularity or observable noise**"[13] was added, characterizing tracings with an isochronic vocal attack. Such an attack occurs when the expiratory phase coincides with the onset of mucosal vibration of vocal folds[26], representing an emission without air leaks or excessive phonatory efforts.

## "Temporal aspects of emission" domain

The second domain evaluated was "**Temporal Aspects of Emission**", created with the intention of gathering the items that described the behavior of vocal signals in the spectrographic tracing over time. This domain allows understanding the variation of energy and noise and the morphological aspect of the harmonics along a vocal emission[30,31]. Physiologically, the concept underlying this domain relates to the maintenance, in time, of the closed phase of glottic cycles and the amplitude of vibration of the mucosa, as well as the vibratory periodicity of the vocal folds[32].

This domain contains three items. Of them, two were considered excellent and one was judged as poor in clarity. As for relevance, two items were evaluated as excellent and one obtained a good classification.

The item "**Presence of tracing irregularity**" was considered excellent as for clarity and relevance. Such results can be justified by the relation of this item to the presence of voice disorders, as demonstrated by several studies[11,12,29]. The tracing is considered irregular when fluctuations in energy and noise behavior are observed along the emission[6], relating to the intermittent presence of a voice quality parameter[14] or to a fluctuation in emission[6].

The item "**Gradual loss of tracing definition/ energy**" was considered excellent as for clarity and relevance. Physiologically, there is a difficulty in maintaining the closed phase of glottic cycles and the vibratory periodicity. In the perceptual plane, this item is associated with a progressive decrease of loudness and an increase in the noise component.

Patients with hypokinetic neurologic conditions commonly have difficulty initiating and maintaining glottic closure and vocal fold vibration[9], which may lead to a tracing showing a gradual loss of energy. Patients with lesions on the free edge of vocal folds also present difficulties in maintaining the regularity of vibration along the vocal emission[33].

The judges considered the item "**Presence of abrupt interruptions in tracing**" as poor in clarity and good as for relevance. This item has a physiological correlate associated with an excessive glottic and/ or supraglottic constriction[34]. In the perceptual plane, it corresponds to sound loss with the presence of acoustic silence in the spectrographic tracing.

A study[34] developed to determine the usefulness of spectrographic analysis for the differentiation of patients with muscle strain dysphonia and patients with adductor spasmodic dysphonia reported that the presence of abrupt interruptions in the spectrographic graph were the main finding to differentiate such cases of spasmodic dysphonia.

Thus, considering the relevance of this item, its value in the differential diagnosis of spasmodic dysphonia and the fact that the description of this item is semantically identical to that found in the literature[34], we suggested keeping this item and its reassessment in a later stage of this research.

According to the suggestion of the judges, one item was added. It characterized a vocal emission without changes as to the temporal aspect. It was titled "**Presence of regular spectrographic tracing**". This item will be evaluated in a later stage of this research.

## "Distribution of energy in the tracing" domain

The third domain evaluated was "**Energy distribution in the tracing**", which covers items related to energy tracing characteristics. It is important to demonstrate the contribution of vocal tract resonance in the spectrogram[9,10]. The theoretical principle underlying this domain is related to a transformation of airflow into sound energy and its change as it passes through the vocal tract.

This domain contains eight items. Of these, six were judged as excellent and two as good as for clarity. Regarding relevance, all items were considered excellent.

The first item of this domain, "**Presence of light harmonics or with a weak degree of darkening**", obtained good CVI-I as for clarity and excellent as for relevance, showing an important and pertinent aspect of the spectrographic vocal evaluation.

Clear or lackluster harmonics may be related to inefficiency of glottic closure, inefficient use of resonance cavities and/or decreased sound pressure[8,35]. This characteristic can be found not only in individuals with speech disorders, but in speakers who do not use the voice professionally or have performed previous vocal training[11]. A rich series of harmonics with brightness is associated with a better glottal closure and a better vocal projection[10].

Although this item has received a good judgment as for clarity, judges have commented on the use of two terms ("light" and "weak degree of blackness") to describe the same signal behavior, which may be confusing at the time of assessment. Thus, considering this suggestion, we proposed to adjust the item title to "**Presence of harmonics with low brightness**", since this terminology is recurrent in the literature[10,11].

The item "**Decreased energy and number of harmonics above 4,000 Hz"** was evaluated as good as for clarity and excellent as for relevancy. The presence of harmonics above 4,000 Hz is very specific to emissions with vocal projection and high loudness[8], with a higher occurrence in individuals who use the voice professionally in conditions that demand projection, such as actors, singers and teachers, and people who received vocal training[11]. Thus, the decrease in the number of harmonics within this frequency range does not necessarily characterize a deviated vocal quality, but may be a typical characteristic of untrained voices[8].

The third item, "**Presence of harmonics above 4,000 Hz**" was also judged as excellent as for clarity and relevance. This description is related to a good use of resonance cavities and the increase of loudness[9]. As discussed previously, the presence of harmonics above 4,000 Hz is an aspect closely associated with professional voices, especially of individuals who have a vocal demand with a greater projection[8,11]. It is an important characteristic to be observed in the development of a professional voice.

This item may also be related to increased subglottic pressure and phonatory tension. In these cases, in addition to a range of harmonics above 4,000 Hz, there is an irregular tracing, characterizing tension issues[34].

Although items "**Decreased energy and number of harmonics above 4,000 Hz**" and "**Presence of harmonics above 4,000 Hz**" have been selected to compose the initial version of the protocol and were well evaluated at this first stage of content validation, it is understood that they are related to a same signal behavior, but dichotomized between "presence *vs.* decrease". We hypothesize that by the statistical (factorial) analysis of the items, one of them will be excluded, without prejudice to the evaluation of the underlying construct.

The item "**Decreased energy and number of harmonics above 4,000 Hz"** was evaluated as good as for clarity and excellent as for relevancy. In the perceptual plane, this item has a correlate of decrease of loudness[10], hypernasality[9], and presence of vocal quality deviation[10,35]. In the physiological plane, it may correspond to an inefficiency in glottic closure, to the vibratory aperiodicity of vocal folds and to velopharyngeal incompetence/insufficiency[36].

The item "**Increase in energy between 1,000-3,000 Hz**" was judged as excellent as for clarity and relevance. It features spectrographic tracings of more tense voices or with a laryngopharyngeal resonance. Such voices can be confused with voices within a normal variability in the spectrographic graph, since the presence of harmonics within this spectrum range is related to both a good vocal quality and presence of an increased vocal tension in the supraglottic tract[30].

It is also common to observe this characteristic in the tracing of subjects who use pharyngeal constriction to assist vocal projection gains aiming to increase loudness[37]. This adjustment may lead to laryngeal hyperfunction, causing negative impacts on vocal quality. It is an important parameter during vocal evaluation.

The item "**The predominance of the $F_0$ tracing in detriment of other harmonics**" was considered excellent as for clarity and relevance.

The amplitude and brightness of the first harmonic have a direct relation with the duration of the phases of the glottic cycle. Tensed voices tend to have a greater amplitude and brightness of the first harmonic in relation to subsequent harmonics. The inverse occurs with blowing emissions[38].

The item "**Reduced energy level over the entire frequency band along the tracing**" obtained an excellent evaluation as for clarity and relevance. Signals with this characteristic tend to present a breathiness component, decrease of loudness and/or hypernasality[15,36].

Such characteristics may be present in patients with vocal fold paralysis[6] due to an insufficient control of airflow, with a reduction in intensity, changes in the frequency and air-phonoarticulatory incoordination.

The item "**Increased energy level over the entire frequency band along the tracing**" was judged as excellent as for clarity and relevance. It corresponds, in the physiological plane, to an increase in the closed phase of glottic cycles, generating an increase in the glottic adduction and a voice with a tense or hyperfunctional quality[32].

As suggested by the judges, the item "Rich series of regular harmonics up to 4,000 Hz" was added to the protocol to contemplate healthy vocal emissions in the domain "energy distribution in the tracing". Individuals with healthy voices, regardless of whether they use the voice professionally or have vocal training, tend to show a greater number of harmonics up to 4,868.6 Hz (women) and 4,242.6 Hz (men), while diverted voices commonly present harmonics up to 2,000 Hz band[35].

## "Description of harmonics" domain

The domain "**Description of harmonics**" groups the items describing the morphological/structural characteristics of harmonics independent of their variation in the temporal aspect, evidencing aspects related to the closed phase of glottic cycles, amplitude and regularity of vibration of the mucosa of vocal folds[9].

This domain contains four items. Of these, three were considered excellent and one was rated good as for clarity. As for relevance, three items were considered excellent and one was considered good.

The first item in this domain, "**Presence of uneven horizontal striations between harmonics**", was judged as excellent as for clarity and relevance. Such item corresponds to the classical description of "sub-harmonics" referred to by the traditional classifications of the spectrographic graph[4,13] and in most studies using narrow-band spectroscopy[7,9,15,35].

The sub-harmonic is a parameter easy to be identified in the tracing and relevant to the context of vocal evaluation[15]. It is a descriptor commonly associated with vibratory irregularity of vocal folds mucosa, showing a perceptual-auditory correlation of roughness present at emission and/or a more intense vocal deviation[39].

The item "**Presence of indefinite harmonics or harmonic sketch**" was judged as excellent as for clarity and relevance. It is associated physiologically both with the decrease in vocal fold mucosal vibration amplitude and the decrease in vocal amplification of sound by the vocal tract[4,39].

The presence of regular and well-defined harmonics is a characteristic of healthy voices, indicating a better glottal coaptation and a greater regularity in the vibration of the mucosa of the vocal folds[30]. Individuals with the least defined spectrographic tracing may be at an initial process of developing vocal change[10]. Moreover, this descriptor is also important in the process of vocal monitoring, since there is a greater definition of the harmonics before and after vocal intervention[7].

The item "**Presence of low amplitude harmonics**" was evaluated as good as for clarity and excellent as for relevance. This item is related to a decrease in the vocal fold mucosal vibration amplitude, generating poorly defined and low amplitude harmonics, which are characteristic of deviated voices mainly presenting a

roughness component[11]. The amplitude and definition of harmonics are considered indexes[35,38].

The judges stated that the way this item was described caused ambiguity. They questioned whether the description corresponded to a decrease in the number of harmonics or to the morphology of each harmonic. Thus, they suggested that the item be described as "**Predominant presence of low amplitude harmonics**", so that it became clear that the item referred to the morphology of most of the harmonics present in the tracing.

The third item, "**Presence of irregular harmonics**" was judged as excellent as for clarity and good as for relevance. The judges justified this finding for relevance by mentioning the similarity with the item "**Presence of tracing irregularity**" of the domain "**temporal aspects of emission**", which causes redundancy and may be a confusing factor at the time of using the protocol for the description of vocal signals.

The main difference between these items is that the item "**Presence of tracing irregularity**" relates to a change in the behavior of the vocal signal along an emission, referring to the global and time-dependent change in the configuration of the spectrographic tracing, that is, the overall aspect of the tracing is presented differently at different emission times. The item "**Presence of Irregular Harmonics**" refers to individual morphological aspects of harmonics, which are configured irregularly throughout the entire emission.

This irregular morphological aspect of harmonics may be associated with instability, vocal tremor[11] or an increase in phonatory tension[34].

Considering the suggestion of the judges, the item "**Presence of regular and high amplitude harmonics**" was added to this domain to contemplate a healthy vocal emission.

## "Distribution of noise in the tracing" domain

The last domain evaluated was "**Distribution of noise in the tracing**". The description of noise is among the main aspects to be evaluated in a spectrographic graph, since it is related to the presence of roughness and airborne emission, which are important and universal parameters of vocal evaluation[14] and constitute important markers of the presence of vocal and laryngeal changes[2].

Noise is visualized on the spectrogram as a shaded, drizzled or dotted image[10], which may be present in different frequency ranges of the tracing, either throughout the emission or in specific ranges.

This domain contains four items, all considered excellent as for clarity, and only one was considered good as for relevance. All others were judged as excellent.

The first item of this domain, "**Presence of noise among harmonics below 4,000 Hz**" is associated, in the perceptive-auditory plane, with rough voices[10]. The presence of noise in the spectrogram within this frequency range occurs when there is aperiodicity in glottic cycles. It may indicate the presence of a slight degree deviation[13], with a predominance of a rough vocal quality[39].

The item "**Presence of noise among harmonics above 4,000 Hz**" was also judged as excellent as for clarity and relevance. However, judges commented that this item evaluates the same aspects of the next item ("Presence of additional diffuse noise above 4,000 Hz") and that it presents the same perceptual and physiological correlates. In addition, it is understood that undisturbed emissions by individuals who have not undergone previous vocal training or who have used the voice professionally may not present harmonics within this frequency range[8,11], so that the description of this item would be restricted to very specific vocal production conditions.

Thus, considering the comments of the judges and the restricted conditions of use of this item, we decided to exclude it from the protocol, since the concept underlying it will be incorporated into the following item.

The item "**Presence of additional diffuse noise above 4,000 Hz**" was judged as excellent as for clarity and good as for relevance. However, given the overlap of concept with the previous item, it was excluded from the protocol. This item is associated with intensity of vocal deviation[13] and presence of the breathy component in emission[10].

Voices with a moderate and intense deviation tend to progressively present noise within this frequency range. This does not occur with signals with slight deviations[13]. Conversely, there is a decrease in noise at high frequencies of the spectrographic graph before and after vocal therapy[40].

Thus, the choice of this item was made both by the semantic aspect, to contemplate the presence of noise independently of the presence of harmonics within this frequency band, and by its greater reference in studies of this area [9,11].

The item "**Presence of noise in the tracing throughout the vocal emission**" received excellent evaluation as for clarity and relevance. However, the judges commented that this item could be confusing as to what would differentiate it from the previous items of this same domain. It may create ambiguity between the temporal aspect (noise throughout the emission) and frequency distribution (noise in all frequency bands).

Therefore, considering that this item is associated to a substitution of the harmonic structure for noise in the tracing, regardless of the time aspect and frequency bands, we decided to rephrase the item for "**Replacement of harmonics for noise in the spectrographic tracing**".

In the perceptual-auditory plane, this item is related to the intensity of vocal deviation[9,13]. In the physiological plane, it is related to aerodynamic, neurological and biomechanical issues that cause aperiodicity in signals. The more the vocal signal is deviated, the greater the harmonic structure replaced for noise[11].

Finally, considering that the judges suggested that in all domains there was an item related to vocal production without deviation, we proposed to include the item "**Spectrographic tracing with discrete or absent noise among harmonics below 4,000 Hz**".

This description was chosen since, admittedly, even signals without vocal quality deviation originating from the larynx without structural/functional changes may present discrete degrees of aperiodicity, which do not characterize the presence of a voice disorder[11]. In addition, the choice for a specific frequency range in the description of this item is based on the fact that the presence of noise above 4,000 Hz already constitutes a sign of vocal deviation[13].

In general, in the initial content validation process of the spectrographic analysis protocol, the domains and items of the protocol proposed therefrom were judged to be clear and relevant by the judges. The protocol aims to descriptively evaluate a narrow-band spectrographic tracing based on the emission of a sustained vowel, allowing the use of a common nomenclature by evaluators which facilitates the communication and interpretation of the information by clinicians.

Thus, five domains and 25 items (Figure 5) were validated in terms of content (clarity and relevance) containing operational definitions regarding the content addressed during the evaluation of vocal signals, their respective physiological and perceptual correlates and their implications in the clinical context. In relation to the initial proposal, five new items were added, all related to aspects of normality of the spectrographic graph. The CVI-T was 0.80 for clarity and 0.90 for relevance, indicating an excellent theoretical formulation related to the design of the instrument.

The development of the protocol may contribute as a tool for conducting research in clinical speech therapy, serving as a resource during vocal evaluation and as a tool for teaching and training new evaluators, who will use the spectrographic acoustic analysis in the clinical practice and or academic research.

## Limitations and future prospects

One of the limitations of this study was the low number of studies whose object of study is narrow-band spectrographic analysis, which is usually only used as one methodological procedure among others.

We hoped to advance in studies on psychometric analyses of the items of this protocol, including its application by different judges to the evaluation of healthy and deviant voices. In addition, we suggested that further studies be conducted investigating the association between the items of the protocol and the auditory perceptual evaluation of vocal quality, as well as the factorial analysis of the items for the determination of the presence/absence of voice disorders considering different patterns (auditory-perceptual analysis, laryngeal visual examination and vocal self-assessment).

## CONCLUSION

In general, domains and items in the spectrographic analysis protocol have a good to excellent content validity as for clarity and relevance. The final version of the protocol, after this validation step, presents 25 items distributed among five domains.

1) Onset of emission

| | | Item |
|---|---|---|
| a) | ( ) | Presence of noise at the onset of emission |
| b) | ( ) | Dark vertical striations at the onset of emission |
| c) | ( ) | Onset of emission with a high number of irregular harmonics |
| d) | | Beginning of the tracing without observable noise or irregularity |

2) Temporal aspects of emission

| | | Item |
|---|---|---|
| e) | ( ) | Presence of tracing irregularity |
| f) | ( ) | Gradual definition/tracing loss |
| g) | ( ) | Presence of abrupt tracing interruptions |
| h) | ( ) | Presence of a regular spectrographic tracing |

3) Distribution of energy in the tracing

| | | Item |
|---|---|---|
| i) | ( ) | Presence of harmonics with a low brightness |
| j) | ( ) | Decreased energy and number of harmonics above 4,000 Hz |
| k) | ( ) | Presence of harmonics above 4,000 Hz |
| l) | ( ) | Decreased energy or reduced number of harmonics up to 4,000 Hz |
| m) | ( ) | Energy increase between 1,000-3,000 Hz |
| n) | ( ) | Predominance of the tracing of F0 in detriment of other harmonics |
| o) | ( ) | Decreased energy level over the entire frequency range along the tracing |
| p) | ( ) | Increased energy level over the entire frequency band along the tracing |
| q) | ( ) | Rich series of regular harmonics up to 4,000 Hz |

4) Description of harmonics

| | | Item |
|---|---|---|
| r) | ( ) | Presence of irregular horizontal striations between harmonics |
| s) | ( ) | Presence of undefined harmonics or harmonic sketches |
| t) | ( ) | Predominant presence of low amplitude harmonics |
| u) | ( ) | Presence of irregular harmonics |

5) Distribution of noise in the tracing

| | | Item |
|---|---|---|
| v) | ( ) | Presence of noise between harmonics below 4,000 Hz |
| w) | ( ) | Presence of additional diffused noise above 4,000 Hz |
| x) | ( ) | Replacement of harmonics for noise in the spectrographic tracing |
| z) | ( ) | Spectrographic tracing with a discrete or missing noise between harmonics below 4,000Hz |

**Figure 5.** Spectrographic Analysis Protocol: version after the content validation stage.

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