VOXPlot: A New System for Acoustic Voice Analysis. Brief Introductory Guide by GIVoC

Erennio Natale[1 2], Chiara Pavese[2], Annamaria Bellomo[2], Serena Calabrese[2], Annamaria Cimmino[2], Giuliana Pisanu[2], Jörg Mayer[3], Ben Barsties v. Latoszek[4], Franco Fussi[1 2]

[1] *Laboratorio della Voce e del Linguaggio - Studio Medico, Ravenna, Emilia Romagna, Italia;*
[2] *Gruppo Italiano Vocologi Clinici (G.I.Vo.C.);*
[3] *Institute for Natural Language Processing, University of Stuttgart, Stuttgart, Germany*
[4] *School of Health, Education and Social Sciences, SRH University of Applied Sciences Heidelberg, Düsseldorf, Germany*

Abstract
Acoustic analysis of voice is a simple, reliable and safe tool for accomplishing the challenging task of quantifying voice quality. To obtain useful information, however, it is necessary to use it appropriately. VOXplot, an innovative free software, is able to guide us in this direction, putting the most complex algorithms—the result of years of scientific research—at the service of the user through an intuitive interface. This introductory guide aims to elucidate and illustrate the potential of the software with the aid of several practical examples and references to parametric signal analysis.

Keywords: *Acoustic Voice Analysis, VOXPlott*

Introduction: Acoustic Voice Quality Analysis

Acoustic voice analysis is a fascinating tool, as it offers the opportunity to 'view' the acoustic signal as a mirror of the vocal cords. It aims to tackle the challenging task of 'quantifying' vocal quality by evaluating the voice phenomenon from a physical standpoint—that is, as a quasi-periodic complex wave—thereby isolating it from all psychoacoustic and emotional components.

There are two primary approaches to measuring voice quality (Barsties, 2014):

1) Perceptual evaluation: This method relies on auditory perception, resulting in a subjective assessment based on rating scales, such as the widely recognized GRBAS scale (Hirano, 1981). Perceptual evaluation is currently regarded as the gold standard in clinical voice assessment (Dejonckere, 1993);

2) Acoustic analysis: This approach uses specific algorithms to objectively quantify different aspects of the vocal signal, either individually or in combination. Acoustic analysis thus provides an objective measure of voice quality. Acoustic analysis is straightforward, cost-effective, non-invasive, and free from contraindications.

VOXplot (Lingphon, Straubenhardt, Germany; https://voxplot.lingphon.com) (Barsties, 2023) is a new, user-friendly, free software optimized for acoustic voice analysis. It uses the same algorithms as Praat (Paul Boersma and David Weenink; Institute of Phonetic Sciences, University of Amsterdam, The Netherlands), but offers a more intuitive interface designed to simplify use for clinicians and researchers. Praat is widely used in linguistics for phonetic analysis and is highly versatile—acoustic voice analysis is just one of its applications—but its extensive functionality can make it complex. VOXplot, in contrast, is focused exclusively on parametric voice quality analysis, specifically calculating the Acoustic Voice Quality Index (AVQI) (Maryn, 2010) and the Acoustic Breathiness Index (ABI) (Barsties, 2017). While VOXplot's narrower scope might limit user options (e.g., spectrogram analysis window adjustments and script modifications are unavailable), its streamlined design is particularly valued by those conducting acoustic analysis for the first time. Despite its simplicity, VOXplot maintains scientific rigor, employing reliable algorithms from Praat, a highly respected acoustic analysis software.

Towards VOXplot: Multiparametric Acoustic Indices

Complex acoustic parameters, such as multiparametric indices, analyze sustained vowels (SV) and continuous speech (CS) simultaneously. Together, these sounds form what is called a "concatenated sample." This combined approach arose from a practical need: over the years, a vast array of parameters has been used to quantify vocal quality (Buder, 2000), yet many fail to correlate effectively with perceptual qualities like hoarseness and breathiness, which are crucial in clinical applications. Recent meta-analyses (Barsties, 2018; Maryn, 2009) indicate that only a handful of the numerous indices used in parametric analysis reliably represent the vocal quality perceived by the human ear, yielding clinically meaningful outcomes. A pertinent example is the variability in how well traditional perturbation indices (such as jitter, shimmer, and harmonics-to-noise ratio, or HNR) correlate with GRBAS scale scores (Grade, Roughness, Breathiness, Asthenia, and Strain) (Hirano, 1981), especially G, R, and B. This correlation fluctuates between acceptable and mediocre, depending on the specific type of jitter, shimmer, or HNR considered. By contrast, certain cepstral and spectral parameters in the frequency domain exhibit more consistent clinical relevance. Although sustained vowels are easier to obtain and minimally influenced by linguistic variability, an objective indicator of vocal characteristics becomes more robust and ecologically valid—that is, more representative of real-life voice use—when it also incorporates continuous speech (Maryn, 2010).

Hence, in 2010, the Acoustic Voice Quality Index (AVQI) (Maryn, 2010) was introduced as a multiparametric index developed to provide a clinically effective measure of overall voice quality, particularly as it relates to dysphonia severity. Despite its relatively recent development, AVQI has proven to be a robust, reliable method for identifying and quantifying dysphonia severity (Batthyany, 2022).

The AVQI score is calculated from a weighted combination of six parameters derived from analyses of both sustained vowels and continuous speech in concatenated samples:

*AVQI 03.01 = (4.152 – 0.177*CPPs - 0.006*HNR – 0.037*shimmerlocal% + 0.941*shimmerlocaldB + 0.01*slope + 0.093*tilt)*2.8902*

This parameter is particularly comprehensive, capturing six variables across time domains (such as shimmer and HNR values), frequency domains (including spectral parameters like slope and tilt), and cepstral peak prominence (CPPS). This balanced mix of "traditional" and contemporary parameters has demonstrated strong correlations with perceived dysphonia.

In the AVQI's initial validation study (Maryn, 2010), researchers examined 13 of the most robust indices from previous meta-analyses and found that this particular combination of six parameters, weighted as shown, offered the best correlation with clinical observations, accurately reflecting the overall degree of perceived dysphonia (notably, the "G" component of the GRBAS scale). The AVQI produces a single score ranging from 0 to 10, where 0 represents optimal (euphonic) voice quality and 10 indicates severe dysphonia. For Italian speakers, the cut-off value between healthy and dysphonic voices is set at 2.35 (Fantini, 2023).

Similar to AVQI but structured to assess "breathiness" rather than the overall degree of dysphonia, the Acoustic Breathiness Index (ABI) is a multiparametric model introduced in 2016 (Barsties, 2017). In the foundational study, a combination of nine parameters was identified that correlated best with perceived breathiness (the "B" component of the GRBAS scale). These parameters were combined in the formula below:

*ABI = (5.0447730915 − [0.172*CPPS] − [0.193*Jit] − [1.283* GNEmax-4500 Hz] − [0.396*Hfno-6000 Hz] + [0.01*HNR-D] + [0.017*H1-H2] + [1.473*Shim-dB] − [0.088*Shim] − [68.295*PSD])*2.9257400394*

Like the AVQI, the ABI formula produces a score from 0 to 10. Here, a lower score indicates a healthier, less breathy voice, while higher scores suggest greater degrees of dysphonia. Validated across more than ten languages, including Dutch, German, Spanish, and Portuguese, the ABI has proven to be a reliable, objective measure with high sensitivity and specificity. It is particularly useful in cases involving benign vocal fold lesions, recurrent paralysis, or adductor insufficiency associated with presbyphonia (Barsties, 2021).

The ABI calculation integrates parameters across various acoustic domains. Besides some of the aforementioned parameters, the ABI formula also takes into account:

- GNE (glottal-to-noise-excitation) (Michaelis, 1997): This metric estimates the degree of vibration due to vocal fold oscillation relative to turbulence, merging spectral and perturbation measurements. Specifically, GNEmax-4500 Hz considers frequencies up to 4500 Hz. Lower GNE values suggest a higher degree of breathiness.
- Hfno-6000 Hz (high-frequency noise-6000 Hz) (dB): This is the ratio of energy intensity (dB) between the 0-6000 Hz and 6000-10000 Hz bands. Measuring these broad frequency ranges helps to detect wide-band noise and remains relatively independent of F0 detection, as each band includes multiple harmonics. Lower Hfno values correlate with higher degrees of breathiness.
- HNR–D (harmonics-to-noise ratio, according to Dejonckere and Lebacq) (dB): This parameter evaluates the prominence of harmonic content within the 500-1500 Hz range, using cepstral analysis for F0 determination. Higher values indicate lower degrees of breathiness.
- H1–H2 (dB): Calculated as the amplitude difference between the first and second harmonics in the spectrum, with higher values indicative of increased breathiness.
- PSD (period standard deviation) (ms): A short-term frequency perturbation index representing changes in period variability; higher PSD values indicate greater irregularity and breathiness.

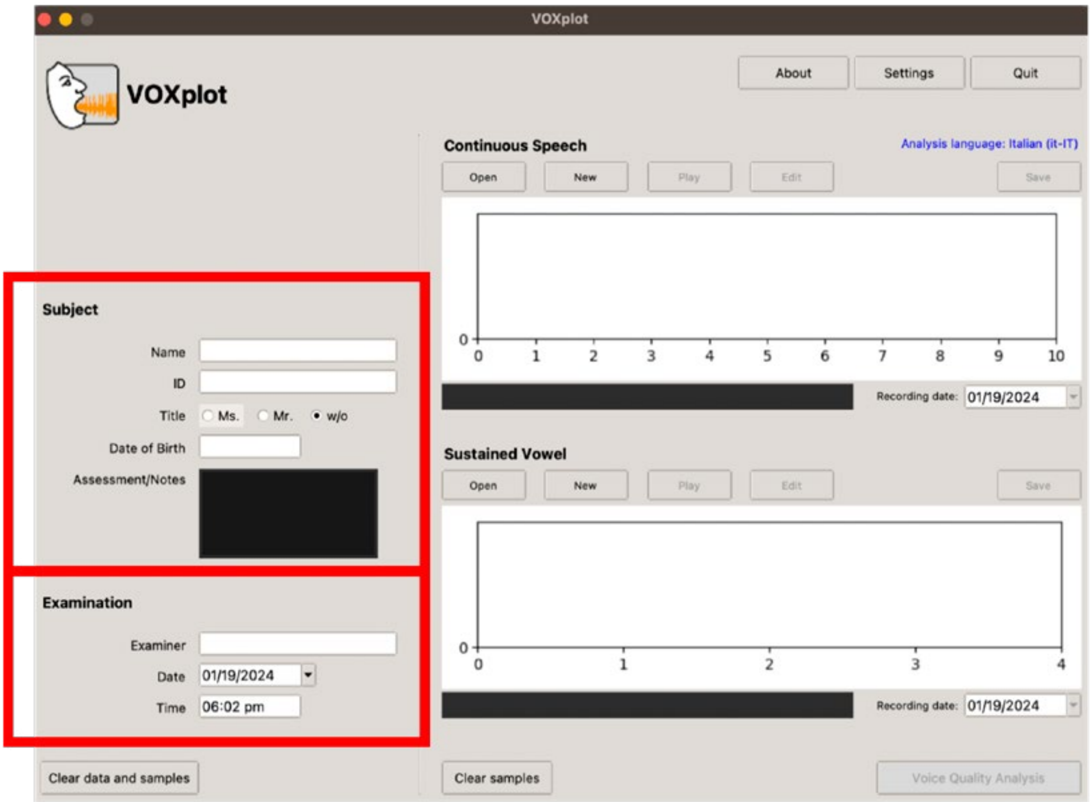

Figure 1. VOXplot home interface. The red rectangles highlight the sections for the patient's personal details, information on the clinician, and the time and date

As with the AVQI, there are parameters of various kinds in the ABI calculation: spectral and cepstral (Hfno, HNR–D, H1–H2, slope, tilt, CPPS), frequency perturbation (PSD, jitter) and intensity perturbation (shimmer) parameters as well as other ones, like GNE, that combine spectral and perturbation analysis. This approach combines “classic” metrics (such as shimmer, which has a strong historical association with breathiness) with newly identified indices (e.g., CPPS and GNE), shown by recent meta-analyses to be the best breathiness predictors (Barsties, 2023; Barsties, 2018).

The ABI validation study for Italian, conducted by the Gruppo Italiano Vocologi Clinici (GIVoC), established the ABI cut-off for distinguishing between healthy and dysphonic voices at 3.34 (Natale, 2023). ABI has proven to be a robust and valid measure for assessing breathiness in Italian voices, displaying satisfactory concurrent validity and high diagnostic accuracy within the Italian-speaking population.

As mentioned, the analysis is conducted on the concatenation of the central three seconds of a sustained vowel [a:] (“SV”) and the vocalized component of continuous speech (“CS”). Due to the phonetic and acoustic peculiarities of each language, the “CS” segment must consist of a standardized text that is both phonetically balanced and of similar duration to the three-second “SV” segment. For the Italian language, the standardized text for continuous speech includes the first two sentences from the CAPE-V (Mozzanica, 2013; Schindler, 2006):

“Il nuovo libro verde è sulla scatola”

“L’uomo e la donna mangiano le uova”

VOXplot: a Practical Guide

VOXplot covers the entire workflow, from recording acquisition (which can include either SV or CS) to the parametric analysis of speech quality using indices (such as AVQI and ABI) validated by the latest scientific research as effective predictors of dysphonia. VOXplot then generates PDF reports, including a spectrogram of the sustained vowel sound. Like many freeware applications, VOXplot is available for all major operating systems.

Upon opening VOXplot (figure 1), the user should first set the correct language for analysis by navigating to Settings (top right) > Language and selecting “Italian” (IT). This language setting optimizes the program for Italian voice analysis (e.g., it loads the appropriate continuous speech texts, cut-offs, etc.). However, this setting does not change the interface language itself. Once the language is selected, other settings are pre-configured for Italian, including a default sampling rate of 44,100 Hz. VOXplot automatically selects the default microphone, which must be connected before launching the program. If VOXplot does not detect the desired microphone, users should select it manually as the recording device in the computer’s system settings before starting VOXplot.

VOXplot then prompts the user to record both SV and CS samples. As in Praat, users have the option to record directly within the software (“New”) or open a pre-recorded file (“Open”). Unlike Praat, VOXplot does not require specific file naming conventions for performing analyses. To record continuous speech or a sustained vowel, select New > Record in the recording window. VOXplot guides users step-by-step through the standardized recording process, as follows:

- The continuous speech recording window displays the standard phrases to be spoken: “Il nuovo libro verde è sulla scatola” and “L’uomo e la donna mangiano le uova”.
- In the sustained vowel recording window, after recording the [a:] sound, users can select three seconds using a preset bounding box, which cannot be extended to a longer duration.

Once the file has been recorded or opened, it can be edited by adjusting the selection box. For continuous speech recordings, silent segments at the beginning or end can be trimmed. The final step in preparing the vocal sample is to click “Accept” to return to the main window. Here, users can listen to the recorded or imported files by selecting “Play” or make further adjustments using the “Edit” button. On the left side of the screen, the personal details of the patient and the name of the examiner can be entered.

After uploading the two recordings, a green button will appear at the bottom right that says "Voice Quality Analysis". Clicking on it will generate the "Acoustic Voice Quality Profile" (AVQP) after about a minute. This summary screen is intended to constitute a "vocal identikit" (or "profile") of the subject, in which the following information is provided (Figure 3):

- The personal details of the patient and examiner (if entered) at the top.
- The spectrogram, with a long analysis window already preset, and the corresponding oscillogram placed below.
- The parameters obtained from the analysis with the relative cut-offs, where available, alongside in green. If a param-

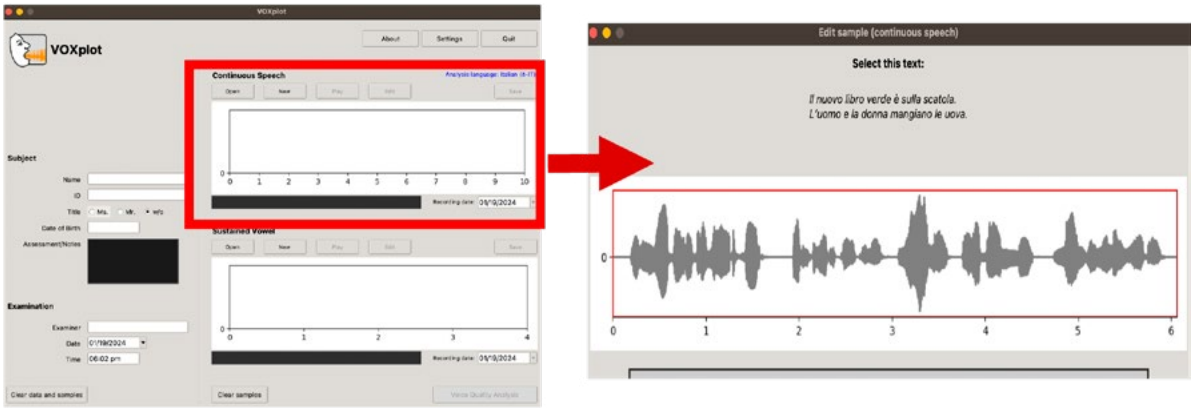

Figure 2. How to record continuous speech using VOXplot

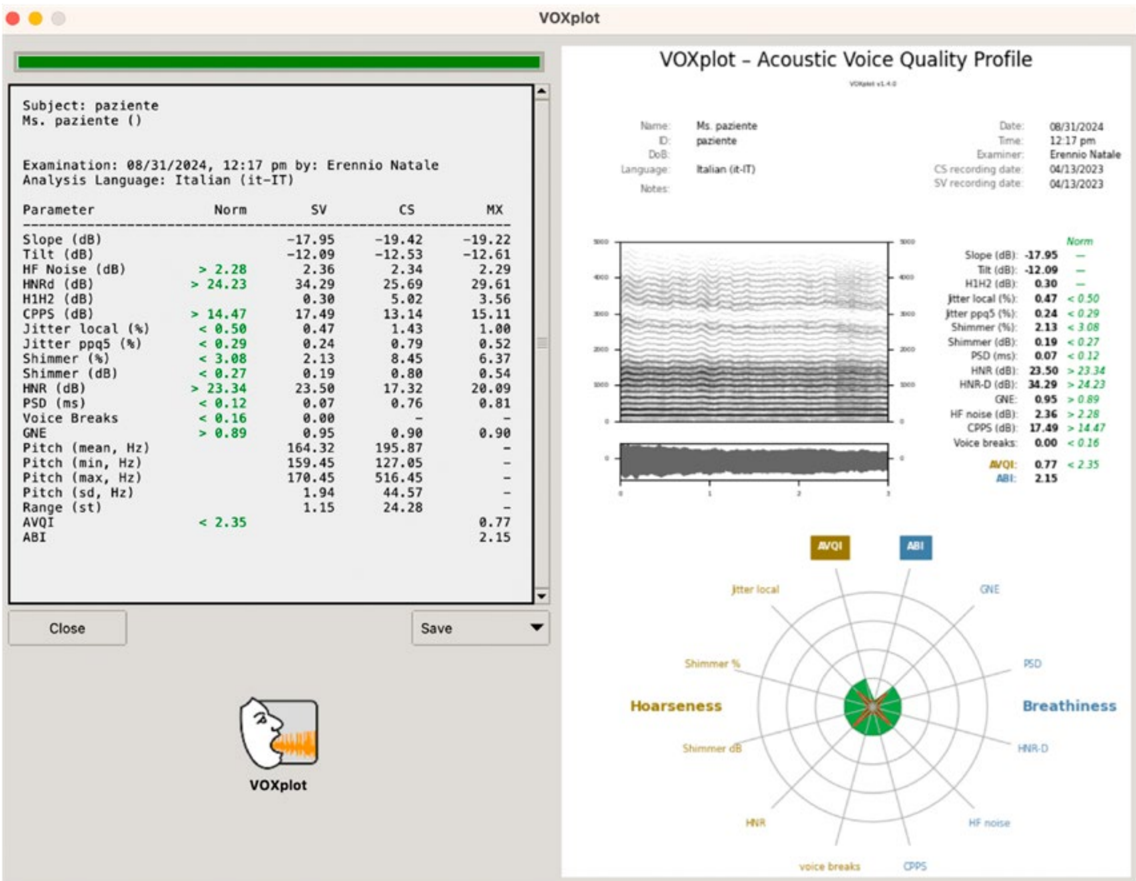

Figure 3. Screenshot overview of voice quality analysis with VOXplot. On the right is a saveable and printable Acoustic Voice Quality Profile (AVQP), and on the left, the extended table with the values of the parameters calculated for the different voice samples (SV, CS, MX).

eter exceeds the regulatory value, it is highlighted in red.
- A summary graph, inspired by the historic "vocalgram" of the Multi-Dimensional Voice Program (MDVP; Kay Pentax, Lincoln Park, USA), which illustrates some of the parameters in the AVQP with an intuitive colour scale (in which green corresponds to the "euphonic" values, within the cut-off, and red to the indicative values of dysphonia that exceed the cut-off).

Finally, the final screen can be exported by clicking on Save > PDF.

The parameter values (and respective normality ranges) are specific to the vocal sample type (CS or SV) most suited for the analysis. For instance, jitter values and the relevant cut-offs displayed are specific to sustained vowels, while AVQI and ABI are calculated from the concatenated sample. The CPPS is calculated on the SV sample, with a normative cut-off set at 14.47 dB for Italian sustained vowels, and so forth (Barties, 2023).

However, it is possible to retrieve a different value from the program's default standards (e.g., CPPS calculated on continuous speech) by consulting the table on the left, which displays all parameters calculated for SV, CS, and the concatenated sample ("MX"). This table also provides useful data, including the average fundamental frequency (Pitch, mean), minimum fundamental frequency (Pitch, min), maximum fundamental frequency (Pitch, max), pitch variability as expressed in standard deviation (Pitch, SD), and the vocal range (Range).

The parameters selected for the Acoustic Voice Quality Profile are those that recent meta-analyses have identified as the most reliable predictors of dysphonia, correlating closely with overall voice quality and breathiness levels. They contribute to the calculation of the multiparametric indices AVQI and ABI. In the summary graph, parameters are schematically divided with those related more directly to general voice quality (AVQI) on the left, and parameters linked specifically to breathiness (ABI) on the right (e.g., GNE, PSD, HNR–D, HF noise, CPPS). This division is purely indicative, as some parameters, such as shimmer or CPPS, contribute to both AVQI and ABI.

In the latest VOXplot versions, the graph has been further simplified (Figure 4), highlighting only pp5 and HNR jitter as indicative parameters of hoarseness, while GNE and CPPS serve as indicators of breathiness. According to recent studies, these are the parameters that, when considered individually, best predict global dysphonia and breathiness, respectively (Barsties, 2023).

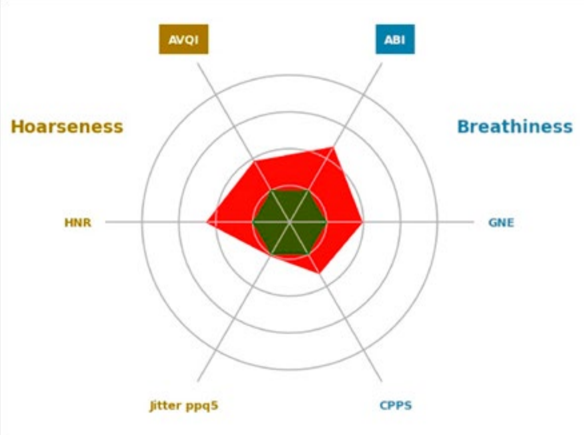

Figure 4. The summary graph present in the most recent versions of VOXplot, which considers only: HNR and pp5 jitter, as the best single predictors of global dysphonia; GNE and CPPS, as the best single predictors of breathiness.

Application of VOXplot and Discriminatory Power of AVQI and ABI

The following examples illustrate the application of VOXplot and the use of multiparametric acoustic models.

Figure 5 presents the Acoustic Voice Quality Profile (AVQP) of a 51-year-old female patient diagnosed with right recurrent laryngeal nerve paralysis. The profile reflects successful compensatory adaptation, evidenced by an AVQI score well below the diagnostic cut-off of 2.35. The spectrogram reveals a predominantly periodic signal with harmonics consistently prevailing over interharmonic noise, extending up to 4000 Hz. This pattern corresponds to a type I according to Sprecher's classification and class 0 according to Yanagihara's scale (modified by Ricci Maccarini and De Colle) (2008). However, a slight degree of air leakage between harmonics results in an ABI score marginally above the threshold of 3.34, highlighting the sensitivity of ABI to subtle breathiness features.

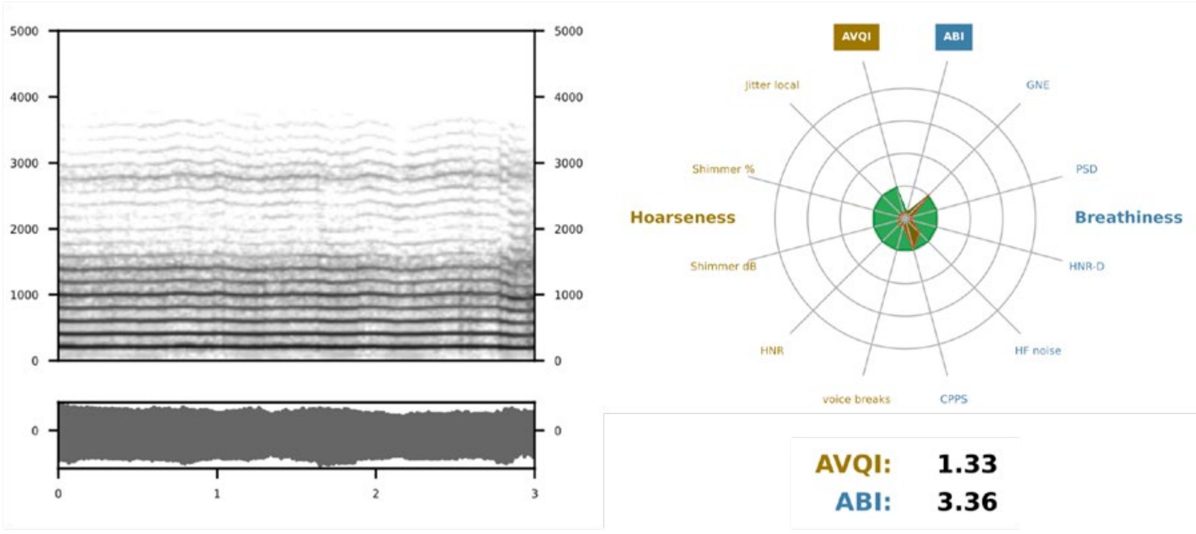

Figure 5. AVQP of a 51-year-old female subject suffering from right recurrent paralysis

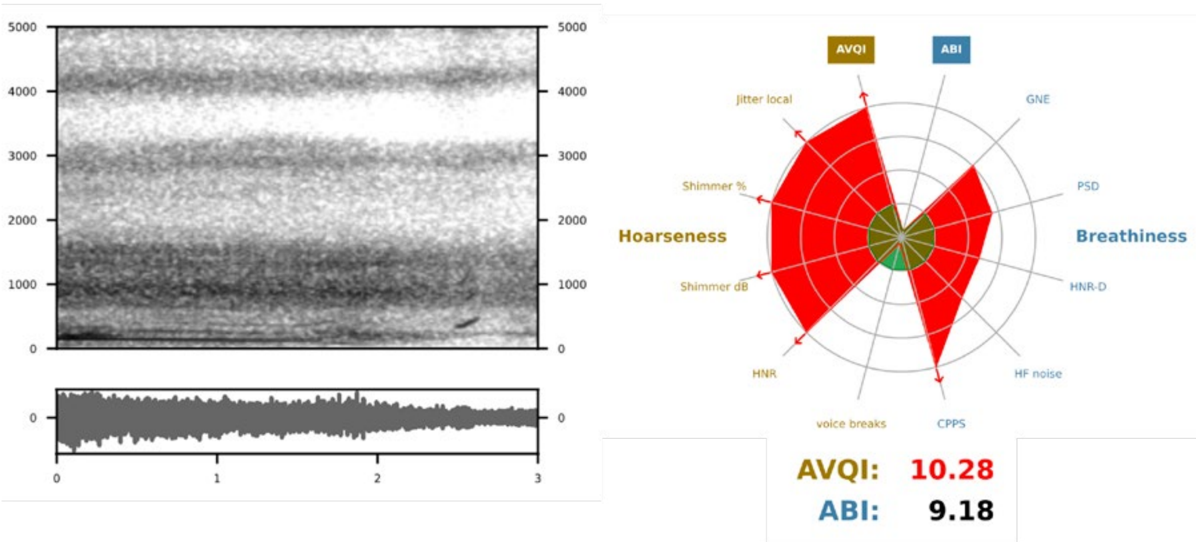

Figure 6. AVQP of a 47-year-old female subject with unilateral uncompensated chordal palsy, with ipsilateral arytenoid dislocation

Figure 6 shows a case involving uncompensated unilateral vocal fold paralysis with ipsilateral arytenoid dislocation. The spectrogram in this profile is markedly disrupted, exhibiting an almost entirely aperiodic signal (type IV per Sprecher's classification, class 5 on Yanagihara's scale), with harmonics barely discernible throughout the vocal emission. This pronounced aperiodicity is reflected in significant deviations in both AVQI and ABI scores.

Figure 7 presents the profile of a 36-year-old male patient with bilateral vocal fold varices. The distinctive hoarseness and breathy quality of the voice are evident in the spectrogram, which displays prominent interharmonic noise from air escape and a loss of harmonic structure above 2000 Hz (type II in Sprecher's classification, class 2 in Yanagihara's scale). Both AVQI and ABI indices are elevated, yet the breathy timbre, more than hoarseness, results in a more pronounced ABI alteration relative to the AVQI.

In Figure 8, we observe a contrasting example where hoarseness is more prominent than breathiness: this is the profile of a patient who underwent a partial horizontal laryngectomy (OPHL IIb + ARY type) (Succo, 2014), with resection above the cricoid cartilage involving the epiglottis and one arytenoid. Post extensive speech therapy, these patients often adapt to phonate via the residual laryngeal structures, forming a "neoglottis." As these structures, covered by mucosal tissue, are not originally designed for phonation, the resulting "neo-voice" is notably hoarse, sometimes harsh, and frequently aperiodic. While acoustic analysis becomes less reliable with increasing aperiodicity, the multivariate indices still align with perceptual evaluations. Here, the AVQI reflects a more pronounced overall voice quality alteration than the ABI, as breathiness is less dominant. The spectrogram, despite trending towards aperiodicity, reveals faint harmonic organization within the first 500 Hz range (classified as type III by Sprecher and class 3 by Yanagihara).

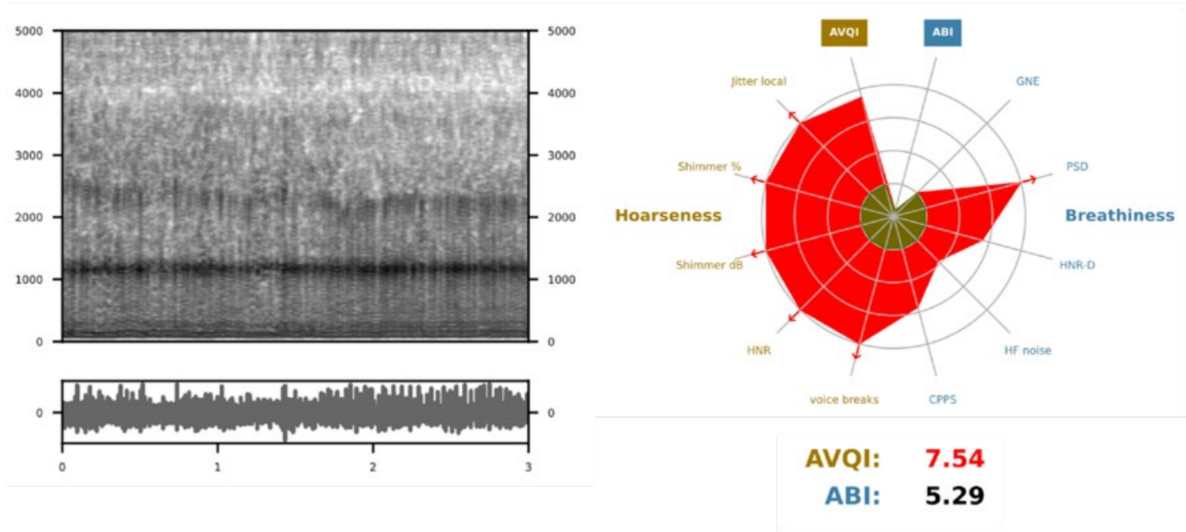

Figure 8. AVQP of a 42-year-old male subject who underwent horizontal partial laryngectomy (OPHL IIb + ARY type)

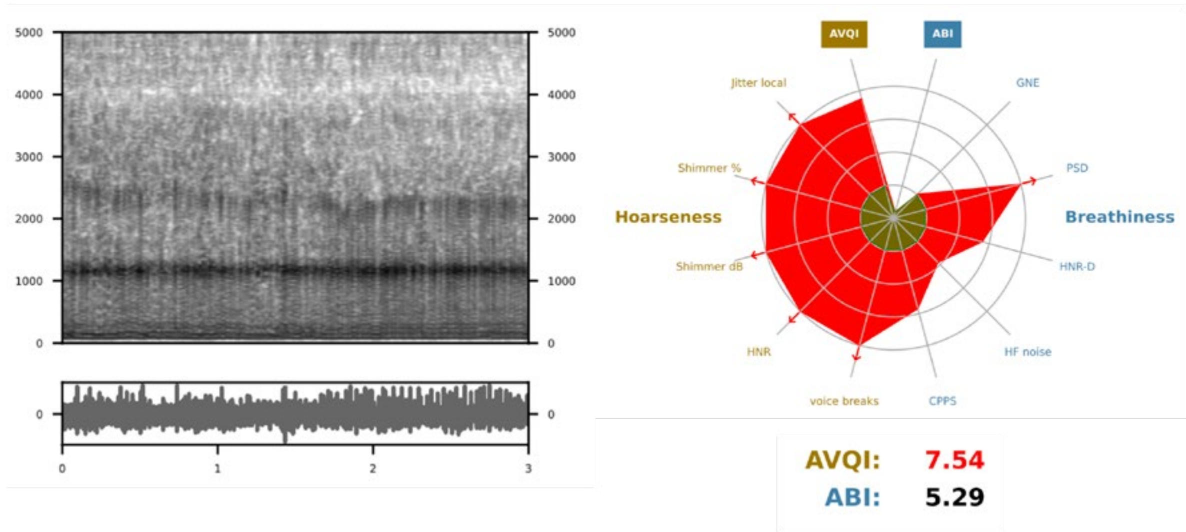

Figure 8. AVQP of a 42-year-old male subject who underwent horizontal partial laryngectomy (OPHL IIb + ARY type)

Conclusions

Acoustic analysis provides a reliable, safe, non-invasive, and cost-effective means of objectively evaluating vocal quality. However, to yield clinically meaningful information, it is essential to apply this tool appropriately, with an understanding of the underlying principles. VOXplot, an innovative and freely available software, facilitates this process by offering complex algorithms—derived from extensive scientific research—through a user-friendly interface.

However, it is important to note that proper voice analysis requires a multidimensional approach. This involves integrating medical history, perceptual evaluation, endoscopy, and aerodynamic assessment, in which the human ear remains the most refined evaluative instrument.

Conflict of interest

Jörg Mayer is the developer of the software, VOXplot, and the owner of the company lingphon.de (Straubenhardt, Germany). Ben Barsties v Latoszek created the ABI and contributed to the development of AVQI v.03. He also acts as a scientific advisor in the creation of the VOXplot software.

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