ORIGINAL ARTICLE

Objective dysphonia evaluation using the EVA® workstation. A review.

Antoine Giovanni[1], Ping Yu[2], Joana Révis[1], Marie-Dominique Guarella[1], Bernard Teston[3], Maurice Ouaknine[1]

[1] Laboratoire d'Audio-Phonologie Expérimentale et Clinique de l'Université de la Méditerranée
CHU Timone Marseille. France
[2] Service ORL - Hôpital de l'Armée de Libération Populaire, Fu-Xing Lu Beijing. China
[3] Laboratoire Parole et Langage - CNRS-Université de Provence, Aix-en-Provence. France

ABSTRACT

Hypothesis: Objective dysphonia assessment can be used to analyze voice quality, similarly to audiograms for analyzing hearing.
Study objective: Advances in tools for objective voice assessment can be used to develop multiparametric voice-analysis protocols based on acoustic and aerodynamic measurements. Our objective was to evaluate a multiparametric protocol comparatively with perceptual analysis by a panel of listeners.
Methods: Voice samples from 270 women with dysphonia and 38 female controls and from 121 men with dysphonia and 20 male controls were subjected to perceptual analysis by a panel of experts and to objective evaluation using acoustic measurements (jitter, Lyapunov exponents, signal-to-noise ratio, and vocal range) and aerodynamic measurements (oral air flow and estimated subglottic pressure).
Results: Discriminant analysis showed concordance between the objective assessment and the perceptual analysis in 81% of women and 84% of men.
Conclusion: Despite difficulties in comparing the continuous speech evaluated by listeners and the sustained vowel sounds used for objective measurements, the use of aerodynamic variables and of nonlinear dynamics has improved the concordance between perceptual and objective evaluations.

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Keywords: Objective voice assessment, Voice, Dysphonia, Panel of listeners.

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Corresponding author: Antoine Giovanni
Laboratoire d'Audio-Phonologie Expérimentale et Clinique de l'Université de la Méditerranée,
CHU Timone Marseille, 13385 Marseille cedex 5. France
e-mail: antoine.giovanni@ap-hm.fr

INTRODUCTION

Reliable assessments of dysphonia are essential to compare diseases, patients, or treatments. Available dysphonia assessment methods range from perceptual analysis and self-evaluation questionnaires to a variety of objective measurements [revue in 1].

Here, we report a method for objective dysphonia assessment based on both acoustic and aerodynamic measurements [2]

Many measurement techniques [reviewed in 3 and 4] and multiparametric protocols have been described [5-6]. Although the best protocol is not universally agreed on, most of the available studies share a number of similarities. Thus, perceptual analysis by a panel of listeners served as the reference standard against which the objective parameters were evaluated [5]. In addition, several objective parameters were used, because of measurement variability and of the multidimensional nature of voice [6]. Use of perceptual analysis as the reference standard is warranted, since perception plays a key role in the communicative function of voice [7]. Patients with dysphonia seek medical help because their voice quality is altered; therefore, changes in voice quality should be used to evaluate treatment efficacy. However, variations in individual perceptions of voice quality constitute a major impediment to reliable perceptual analysis, as shown by numerous studies [8].

To capture the multidimensional nature of voice, most studies combined several acoustic and aerodynamic parameters. Evaluations that rely solely on acoustic parameters have proved unreliable. Thus, Wolfe et al. investigated a combination of four acoustic parameters: mean fundamental frequency (Fo), jitter, shimmer, and harmonic-to-noise ratio [5]. Regression analysis showed that concordance between these four parameters (with a major contribution of Fo and shimmer) and perceptual analysis was only 56%, which was not sufficient for clinical use.

Piccirillo et al. investigated a combination of 14 objective acoustic and aerodynamic parameters [6] in 97 patients with dysphonia and 35 controls. The parameters included subglottic pressure, oral airflow, intensity (weak, medium, strong), frequency (lowest, medium, highest), vocal range, laryngeal resistance, maximum phonation time, transglottic airflowrate, and electroglottography. Four variables were significant by regression analysis: subglottic pressure, oral airflow, maximum phonation time, and vocal range. Wuyts et al. used data from a multicenter study conducted in Belgium to develop the Dysphonia Severity Index (DSI) [9]. They investigated 319 individuals with dysphonia due to various conditions and 68 controls. Thirteen objective acoustic and aerodynamic parameters were collected, and perceptual analysis was performed using a four-point scale (0, normal voice; 3 severe dysphonia). Four parameters were significant by multivariate regression analysis: highest frequency (Fo-High, in Hz), lowest intensity (I-Low, in dB), maximum phonation time (MPT, in s), and jitter (%). The DSI was obtained using the following linear regression equation based on these four parameters: DSI = 0.13*MPT (s) + 0.0053*Fo-High (Hz) – 0.26*I-Low (dB) – 1.18*Jitter (%) + 12.4. Values from 0 to -5 indicated increasingly severe dysphonia and values from 0 to +5 increasingly mild dysphonia, with +5 indicating a normal voice. By discriminant analysis, however, concordance between these four objective variables and perceptual analysis was only 56%, which was too low to be useful as a clinical or medico-legal tool.

Since 1990, we have been developing a device and a method aimed at providing clinicians with a tool for voice quality assessment that could serve both for clinical and for medico-legal purposes. Our goal is to obtain an alternative to analysis by a panel of listeners, which is too cumbersome for use in everyday practice. Jointly with the Speech and Language University at the Provence University (UMR CNRS 567), France, we developed the EVA® workstation that uses a special mouthpiece to provide concomitant measurements of acoustic and aerodynamic parameters [2]. We previously described a multiparameter protocol for objective voice assessment using the EVA® system in patients with dysphonia [10]. In this previous study, we included 63 men with dysphonia and 21 controls, in whom we recorded ten objective acoustic and aerodynamic parameters: Fo, intensity, jitter, the Lyapunov exponents (an index of vibratory stability that resembles jitter but does not require previous determination of frequency) [11]), signal-to-noise ratios (SRf>0 and SRf>1kHz), oral airflow, estimated subglottic pressure, vocal range, and maximum phonation time. By discriminant analysis, the objective assessment showed 86% concordance with the perceptual analysis.

This encouraging result was consistent with clinical use of the protocol. Here, we sought to define the combination of objective parameters that best predicted the perceptual analysis grade.

PATIENTS AND METHODS

Study participants

We retrospectively studied voice samples from the voice data bank of the ORL Federation, Timone Teaching Hospital, Marseille, France. We included all the samples from adults that were of sufficient technical quality (most notably free of saturation) to allow a meaningful perceptual analysis. The diagnosis had been established by indirect laryngoscopy using a rigid endoscope (in most cases) or a flexible endoscope (in patients with a strong gag reflex) performed as part of an otorhinolaryngologic evaluation. Stroboscopic illumination was used in difficult cases. The diagnoses included vocal fold dysfunction, organic vocal fold lesions, and unilateral vocal fold palsy. Voice recordings were obtained before medical treatment, surgery, and speech therapy.

Perceptual analysis

Voice samples were recorded in a soundproof room using a digital audiotape recorder (Tascam DA-20, Tascam, Tokyo, Japan). Each study participant was asked to read the first few sentences of a well-known children's book (La Chèvre de M. Seguin by Alphonse Daudet), at a comfortable pitch and volume and as naturally as possible.

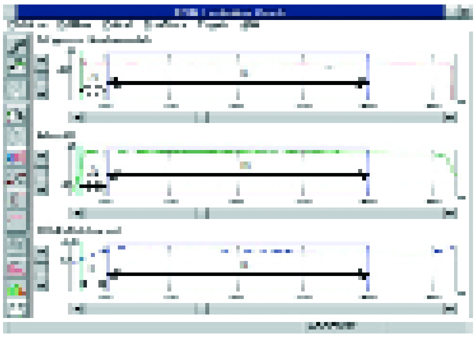
Overall voice quality was analyzed by a panel of listeners, who used a 10-point visual analog scale (0: normal voice; 10: severe dysphonia). The panel was composed of four individuals who had several years of experience with assessing voice quality, two speech therapists and two phoniatrists (physicians specialized in voice disorders). The samples were presented to the panel in random order on three occasions, so that each sample was assessed 12 times (three times by each of four listeners). The best and worst scores were removed and the mean of the 10 remaining scores was computed and converted to a grade as previously described [12]: score 0-1, grade 0 (normal voice); score 1-5, grade 1 (mild dysphonia); score 5-9, grade 2 (moderate dysphonia); and score 9-10, grade 3 (severe dysphonia).

Objective measurements

Objective measurements were obtained using the EVA® system (SQ-Lab, Aix-en-Provence, France). The study participant was asked to utter a sustained /a/ at a comfortable volume and at a pitch as close as possible to the participant's natural voice. After several trials, the examiner selected the utterance believed by the examiner to best replicate the participant's natural voice as assessed perceptually during the reading test. The selected utterance was recorded digitally.

The data were recorded during a 2-second window. The window started 200 ms after signal onset, in order to eliminate instability related to signal onset (Figure 1). The following were recorded: Fo (Hz), intensity (dB), jitter factor (%), oral airflow (cm3/s), signal-to-total noise ratio (SRf>0), and signal-to-noise>1kHz ratio (SRf>1kHz). On the same portion of the signal, we determined the Lyapunov exponents (bits/s) using software that replicates the previously described algorithm [11] based on signal phase portrait analysis. The procedure was performed in triplicate, and the mean of the three values

Figure 1: Signal display on the EVA® system.



Top: frequency vs. time.
Middle: intensity vs. time.
Bottom: oral airflow over time. Selection of the window used to compute the main parameters.
A: the first 200-ms stretch of the signal is not analyzed;
B: 2000-ms window used for the analysis.

was used for the study.

We did not measure shimmer, whose reliability seemed limited with version 1 of the EVA® system, which was the only version available at the time of the study. (We now use version 2, in which a logarithmic manipulation improves the reliability of shimmer measurements.)

Subglottic pressure (hPa) was measured using the sensor in the EVA, system and Phonedit software. A tube was placed in the participant's mouth, and the participant held it between the front teeth, taking care not to squeeze it out of shape. The participant was asked to pronounce the syllable /pa/ ten times, at normal pitch and volume, at a rate of about one per second. The first and last values were eliminated, leaving six values for estimating subglottic pressure.

For each participant, mean estimated subglottic pressure was computed. We determined vocal range by asking the participant to utter two sounds, one with the lowest and the other with the highest possible pitch. The EVA, was then used to determine the pitch of each sound and to compute vocal range as the difference between the two pitches (Hz). For maximum phonation time determination, each participant was asked to utter a sustained /a/, maintaining the utterance as long as possible at comfortable pitch and volume. Cursors placed at the beginning and end of the digitalized signal recording were used to determine phonation time. The mean value of three consecutive trials was used for the study.

Statistical analysis

Systat 7.0® for Windows® (Systat Software Inc., Chicago, IL) was used. For the descriptive analysis, we computed mean values and standard deviations (SDs) in each diagnosis group and dysphonia-severity group. This allowed us to assess the influence of the diagnosis on voice quality compared to the control group. We then conducted a comparative analysis to determine whether the objective parameters effectively discriminated normal participants from patients having dysphonia and accurately discriminated among the dysphonia grades. Several variables were non-normally distributed, and the numbers of patients with each diagnosis varied widely. Therefore, we used the Mann-Whitney nonparametric test to compare the patient groups and the control groups, as well as the groups defined according to dysphonia severity. P values smaller than 0.05 were considered statistically significant. Posthoc discriminant analysis was performed using a previously described algorithm [8].

RESULTS

We evaluated 449 voice samples from 391 patients with dysphonia (270 women and 121 men) and 58 controls (38 women and 20 men). Mean age was 42 years (range, 19-76) in the patients and 38 years (20-62) in the controls. The distribution of diagnoses (Table I) varied markedly between the men and women, precluding comparisons between these two populations. Objective measurement values in the patients and controls are reported in Tables IIa and IIb. Objective measurements are compared to perceptual analysis grades in Table III. The grade was 0 (normal voice) in 49 women, although there were only 38 female controls, and in 25 men, although there were only 20 male controls.

In our retrospective discriminant analysis, we identified the combination of objective measurements that produced the best concordance with the perceptual analysis. To this end, we used a previously described nonlinear algorithm [8]. The parameters that performed best in women in the stepwise phase of the analysis were vocal range, Lyapunov exponents, estimated subglottic pressure, maximum phonation time, oral airflow, SRf<1kHz, and Fo. In men, the best parameters were vocal range, Lyapunov exponents, maximum phonation time, estimated subglottic pressure, Fo, and signal-to-noise ratio. The discrimination tables obtained using these parameters and the algorithm are shown in Tables IV a and IVb. Concordance was 81% in women and 84% in men. Concordance regarding separation of normal voices from dysphonic voices was 93% (117/126) in women and 93% (44/47) in men. We did not test discrimination according to the diagnosis.

DISCUSSION

Our objective was to validate our EVA® measurement protocol in a large population of patients with dysphonia, comparatively to controls. Concordance rates with perceptual analysis were 81% in women and 84% in men, indicating that our combination of

Table I: Distribution of the diagnoses in the female and male patients.
Note the differences between females and males (e.g., nodules in 89 (29%) females compared to only 8 (5%) males)

	Women	Men
Controls	38	20
Functional dysphonia	15	9
Nodules	89	7
Polyps	50	41
Reinke's edema	47	8
Cysts	23	4
Sulcus vocalis	10	4
Unilateral palsy	36	29
Leukoplasia	-	19
Total	**308**	**141**

Table II: Objective measurement values according to diagnosis.

In the groups with organic disease, most of the parameters differed significantly from values in the controls. In contrast, differences were not significant between patients with functional dysphonia and controls.

IIa Women (270 patients and 38 controls)

	n	Fo (Hz)	Jitter (%)	Range (Hz)	LC (bits/s)	Int (dB)	OAF (cm3/s)	ESGP (hPa)	S/N R (db)	S/N R>1khz (dB)	MPT (s)
Controls	38	215 (23)	0.51 (0.41)	418 (124)	112 (68)	87.7 (3.3)	136 (56)	6.6 (1.5)	60.6 (10.9)	23.9 (7.5)	13.4 (5.7)
Functional dysphonia	15	198 (67) *0.313*	0.51 (0.10) *0.525*	405 (142) *0.230*	157 (94) *0.095*	86,6 (5.3) *0.230*	140 (61) *0.747*	6.8 (1.8) *0.960*	53.9 (15.7) *0.247*	18.9 (7.2) *0.040*	11.9 (3.3) *0.565*
Nodules	89	207 (27) *0.086*	0.94 (1.66) *0.004*	275 (145) *0.001*	206 (329) *0.005*	88.8 (5.5) *0.353*	186 (84) *0.001*	8.4 (2.4) *0.001*	54.9 (16.6) *0.083*	18.4 (8.8) *0.001*	10.0 (4.0) *0.001*
Polyps	50	196 (33) *0.005*	1.15 (1.07) *0.001*	202 (95) *0.001*	220 (183) *0.001*	89.3 (4.1) *0.145*	213 (109) *0.001*	12.1 (12.0) *0.001*	54.2 (14.0) *0.032*	15.7 (6.1) *0.001*	7.7 (2.8) *0.001*
Reinke's edema	47	163 (39) *0.001*	2.77 (4.73) *0.001*	166 (57) *0.001*	351 (360) *0.001*	89.7 (5.6) *0.113*	236 (106) *0.001*	10.2 (3.4) *0.001*	47.6 (17.2) *0.001*	12.3 (7.2) *0.001*	7.5 (3.0) *0.001*
Cysts	23	208 (27) *0.382*	1.33 (2,388) *0.001*	251 (102) *0.001*	278 (387) *0.002*	89.7 (6.6) *0.047*	191 (88) *0.011*	10.4 (3.9) *0.001*	52.2 (13.6) *0.035*	15.7 (7.0) *0.001*	7.3 (2.2) *0.001*
Sulcus vocalis	10	229 (36) *0.297*	0.82 (0.50) *0.002*	226 (87) *0.001*	179 (79) *0.006*	90.7 (5.4) *0.147*	216 (28) *0.041*	10.2 (3.9) *0.004*	53.6 (12.4) *0.094*	14.7 (6.3) *0.002*	9.3 (5.3) *0.041*
Unilateral vocal fold palsy	36	220 (43) *0.758*	1.78 (3.27) *0.001*	204 (94) *0.001*	334 (421) *0.001*	87.1 (5.4) *0.435*	244 (147) *0.001*	8.7 (2.9) *0.001*	50.8 (17.7) *0.016*	15.1 (6.6) *0.001*	7.0 (5.7) *0.001*

The values are the means followed by the standard deviation in parentheses and the P value for the patients vs. controls in italic type (Mann-Whitney test). Significant P values (<0.05) are underlined

IIb Men (121 patients and 20 controls)

	n	Fo (Hz)	Jitter (%)	Range (Hz)	LC (bits/s)	Int (dB)	OAF (cm3/s)	ESGP (hPa)	S/N R (db)	S/N R>1khz (dB)	MPT (s)
Controls	20	124 (27)	0.55 (0.15)	320 (120)	151 (75)	91.8 (5.0)	156 (61)	6.3 (1.7)	62.1 (16.2)	20.1 (10.9)	21.7 (7.3)
Functional dysphonia	9	130 (21) *0.528*	0.71 (0.37) *0.370*	355 (135) *0.524*	209 (153) *0.579*	94.1 (7.3) *0.164*	163 (90) *0.850*	7.7 (3.0) *0.069*	45.1 (22.8) *0.085*	17.5 (12.5) *0.505*	19.0 (7.0) *0.493*
Nodules	7	127 (41) *0.839*	1.6 (1,1) *0.049*	301 (178) *0.700*	404 (546) *0.297*	93.4 (5.1) *0.518*	206 (87) *0.174*	10.9 (4.1) *0.013*	49.4 (22.4) *0.205*	13.0 (6.1) *0.264*	14.9 (13.3) *0.393*
Polyps	41	127 (26) *0.510*	3.1 (4.7) *0.001*	138 (92) *0.001*	387 (427) *0.014*	93.2 (6.4) *0.259*	294 (145) *0.001*	10.4 (3.7) *0.001*	53.2 (14.1) *0.054*	14.1 (8.0) *0.046*	9.7 (5.5) *0.001*
Reinke's edema	8	120 (30) *0.740*	2.32 (3.12) *0.319*	125 (76) *0.001*	271 (113) *0.014*	94,0 (4,1) *0,280*	237 (60) *0.008*	12.4 (5.0) *0.002*	60.0 (9.1) *0.689*	18.5 (5.7) *0.689*	8.0 (4.4) *0.001*
Cysts	4	133 (37) *0.699*	1.13 (1.18) *0.486*	150 (72) *0.045*	204 (125) *0.268*	93.3 (6.7) *0.727*	271 (150) *0.075*	14.2 (3.2) *0.008*	56.6 (21.2) *0.551*	18.7 (12.7) *0.670*	10.5 (8.4) *0.067*
Sulcus vocalis	4	171 (20) *0.028*	1.60 (1.74) *0.293*	141 (115) *0.005*	323 (122) *0.021*	93.7 (7.7) *0.749*	318 (156) *0.083*	11.9 (4.9) *0.018*	55.0 (15.8) *0.482*	13.3 (7.4) *0.421*	6.9 (1.7) *0.006*
Unilateral vocal fold palsy	29	151 (33) *0.005*	6.75 (8.53) *0.001*	153 (78) *0.001*	582 (623) *0.001*	90.6 (5.1) *0.555*	474 (287) *0.001*	24.4 (7.5) *0.001*	53.1 (15.6) *0.07*	11.5 (7.3) *0.004*	4.2 (2.7) *0.001*
Dysplasia	19	147 (43) *0.143*	4.97 (3.83) *0.001*	134 (51) *0.001*	1002 (767) *0.001*	87.5 (4.9) *0.041*	232 (118) *0,075*	16.5 (9.5) *0.001*	43.7 (15.0) *0.040*	7.7 (4.4) *0.002*	10.6 (5.4) *0.005*

Table III: Crude means (SD) of objective parameter values in males (M) and females (F) according to grade determined by perceptual analysis.

The large SD values indicate marked within-group variability.

		Grade 0 - F/M (49/25)	Grade 1 - F/M (83/26)	Grade 2 - F/M (141/57)	Grade 3 - F/M (35/33)
Fo (Hz)	F	218 (28)	204 (34)	195 (37)	208 (57)
	M	122 (24)	131 (27)	130 (33)	167 (32)
Int (dB)	F	88 (4)	88 (5)	89 (5)	89 (5)
	M	92 (5)	92 (7)	93 (5)	89 (9)
Jitter(%)	F	0.49 (0.13)	0.60 (0.28)	1.13 (1.53)	4.51 (5.54)
	M	0.55 (0.16)	1.02 (0.65)	2.02 (2.75)	10.58 (13.21)
LC (bits/s)	F	117 (74)	133(76)	249 (291)	622 (536)
	M	156 (83)	217 (141)	323 (251)	950 (1000)
SN-R f>0 (%)	F	58.4 (13.8)	56.7 (14.2)	52.2 (15.4)	40.6 (19.2)
	M	62.1 (14.1)	49.2 (19.2)	58.7 (11.1)	40.7 (14.4)
SN-R (%) f>1kHz	F	23.1 (7.8)	19.2 (7.4)	15.0 (7.2)	10.1 (6.4)
	M	21.7 (9.9)	15.5 (10.3)	15.1 (6.5)	7.0 (4.3)
OAF (cm3/s)	F	136 (58)	168 (59)	210 (102)	305 (151)
	M	153 (66)	191 (69)	322 (162)	446 (287)
ESGP (hPa)	F	6.7 (1.5)	7.7 (2.0)	9.9 (3.2)	11.2 (4.0)
	M	6.7 (1.6)	9.7 (3,4)	10.8 (3.3)	14.2 (4.2)
Range (Hz)	F	410 (127)	316 (130)	199 (87)	168 (81)
	M	294 (133)	215 (136)	141 (86)	141 (81)
MPT (s)	F	13.6 (5.1)	10.5 (4.0)	7.6 (2.9)	5.3 (3.0)
	M	24.0 (8.8)	13.4 (5.0)	9.3 (4.8)	4.7 (2.7)

acoustic and aerodynamic parameters measured using the EVA® is reliable for clinical and medicolegal evaluations of patients with dysphonia. Nevertheless, a number of points deserve discussion.

Variability of perceptual assessments

Each listener has a personal appreciation of voice problems that depends on training (hearing anchor) and listening conditions (the voice of the previous patient and several other factors). Variability across listeners decreases as experience with perceptual analysis increases [12]. Therefore, variability can be decreased by using a panel of experienced listeners. Perceptual analysis by a panel of experienced listeners is currently the most widely used reference standard for voice quality assessment. Because listeners often experience difficulties in classifying patients with intermediate dysphonia grades, we used a visual analog scale score, which was secondarily converted to a grade on a 4-point scale [13]. However, the listener panel method is extremely cumbersome, and alternatives that are better suited to everyday practice are needed. Therefore, the value of objective measurement systems must be determined comparatively to perceptual analysis.

Difference in voice samples used for perceptual analysis and objective measurements

Continuous speech is used for perceptual analysis and a sustained vowel for objective measurements. Clinicians frequently object to this difference, even when the correlation with perceptual analysis is statistically validated. The theoretical framework of perceptual analysis by a panel of listeners is ill-defined. The listeners are asked to assess a quality, such as hoarseness or breathiness, of a continuous speech sample. However, dysphonia does not affect all the vowels in the same way during continuous speech. For instance, in patients with unilateral vocal fold paralysis, vocal-fold approximation and vibration may vary across portions of the sample. As a result, the listener perceives variable degrees of dysphonia across phonemes (i.e., grade 0 for some phonemes and grade 2 for others) and must decide which degree defines the dysphonia grade. The cognitive processes used to make this decision are obscure. The impact of voice samples on perceptual analysis is being investigated by Révis and colleagues [14], although many additional studies are needed. The data from these studies may allow the development of automated signal analysis methods that replicate the cognitive processes used by listeners. Such methods would lead to objective studies of speech, or vowels from speech, instead of isolated vowels.

Table IV. Concordance between dysphonia grade as determined by perceptual analysis and group defined by objective parameters.

IVa Females *(n : 308)*

	Groupe 0	Groupe 1	Groupe 2	Groupe 3	% correct
Grade 0 (n : 49)	**45**	4	0	0	92%
Grade 1 (n : 83)	5	**72**	6	0	87%
Grade 2 (n : 141)	2	19	**104**	16	74%
Grade 3 (n : 35)	0	0	6	**29**	85%
Total	52	95	116	45	81%

IVb Males *(n : 141)*

	Groupe 0	Groupe 1	Groupe 2	Groupe 3	% correct
Grade 0 (n 23)	**22**	1	0	0	96%
Grade 1 (n :26)	2	**22**	2	0	84%
Grade 2 (n :57)	0	10	**42**	5	74%
Grade 3 (n :33)	0	0	1	**32**	97%
Total	24	26	22	12	84%

The numbers of correctly classified study participants are indicated in bold type on the diagonal.

Validity of objective measurements

Objective measurements must meet three criteria: (1) they must carry pathophysiological significance; (2) they must discriminate between normal and abnormal voices; (3) and their results must reflect dysphonia severity [3]. The results reported here confirm that the EVA® system produces reliable measurements of objective parameters: the measurements can be interpreted in terms of pathophysiology and subjected to statistical analysis. Measurements obtained using nonlinear dynamics will be discussed later in this article.

The reliability of objective parameters can be assessed in terms of variability. Variability increases with the severity of dysphonia. Our data support earlier evidence [3-4] that considerable variability may occur, most notably regarding signal instability. At the Workshop on Voice Analysis held in Denver in February 1994, Titze suggested classifying voice signals into three types that may require different objective evaluation methods (unpublished data). Periodic or quasi-periodic signals (type 1, normal or mild dysphonia) remain unchanged throughout the analysis window. In this situation, statistical measurement of periodicity is satisfactory, and only jitter values less than 5% can be considered significant. Type 2 signals, such as those seen in moderate dysphonia, contain subharmonics, modulations, and bifurcations and cannot be defined by the mean Fo. Graphic tools such as spectrograms, phase portraits, and Fo plots are more appropriate but difficult to quantify. Type 3 signals, which occur in severe dysphonia, are chaotic and devoid of periodic components. Perceptual analysis of hoarseness is the only feasible method in this situation. However, this approach is not well suited to medicolegal or clinical purposes, as the severity of dysphonia must be determined first, before using the corresponding measurement approach. This situation would be similar to using different methods and audiometers for obtaining audiograms in patients with mild, moderate, and severe hearing loss. The best means of circumventing this difficulty is multiparametric assessment. However, the main obstacle may reside in selection of appropriate voice material, rather than in the objective measurement method itself. Ideally, all the objective measurements should be obtained for each vowel and the set of measurements should then be processed using a decision-tree based on the cognitive processes used by listeners. Such a decision-tree is not available at present.

In practice, our results are consistent with data in the literature, most notably those reported by Piccirello et al., Wuyts et al., and Dejonckere et al. [6, 9, 15]. Two of the most reliable parameters in these studies were vocal range (and its variants) and maximum phonation time, both of which can be readily determined in everyday clinical practice. Furthermore, all the available studies emphasize the many uncertainties that surround acoustic parameters, which contrast with the reliability of aerodynamic parameters such as oral airflow and estimated subglottic pressure. Our study confirms that computer-assisted voice analysis based solely on acoustic parameters is not reliable at present. However, this conclusion may need to be revised if advances are achieved, most notably regarding spectral analysis and signal-to-noise evaluation.

Parameters obtained using nonlinear methods

The usefulness of nonlinear signal analysis in evaluating dysphonia has been established over the last 10 years by Titze et al. [16], Herzel et al. [17], and Berhman et al. [18]. Our group developed an algorithm for computing Lyapunov exponents [11], which was a key tool in the present study.

Nonlinear dynamics evolved from chaos theory. A description of their theoretical framework and methods would be beyond the scope of this article. The underlying principle is that vocal fold function is not strictly symmetrical and synchronous between the two sides. The small asymmetries, irregularities, and imperfections in vocal fold function can be viewed as degrees of liberty [17-18]. Nonlinear measurements seek to detect the expression (which may be partial) of these degrees of liberty. This objective can be achieved by using new indices, whose pathophysiological significance remains somewhat unclear, such as fractal dimensions [19] and Lyapunov exponents [11]. These indices can be likened to signal stability indices, such as jitter and shimmer for instance. However, they do not require previous determination of frequency, which varies considerably in dysphonia. The next few years will witness the emergence of new concepts that will serve to validate nonlinear methods and to clarify their clinical significance and relevance.

CONCLUSION

A multiparametric objective voice analysis protocol is available for adding to the perceptual analysis of patients with dysphonia and of their physicians. Our study confirms that two classic parameters, maximum phonation time and vocal range, are highly relevant and reliable. Flow and pressure measurements are useful adjuncts, although they require costly equipment. Finally, nonlinear signal analysis methods are useful and will no doubt take on growing importance in the near future.

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