

DOI: 10.4172/1791-809X.1000100420

Functional Examination of Voice, a Review

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Received: 18.04.2016; Accepted: 05.07.2016; Published: 15.07.2016

Abstract

The purpose was to compare different quantitative methods to determine diagnoses of laryngeal disorders in a better way. Stroboscopy with its low amount of pictures of movements of the 25 pictures pr. second of vocal folds cannot show correct functions of the larynx. This paper evaluates high speed films with 4000 pictures per second, kymography with a graphical representation of spatial position over time of the vocal folds seen from above, calculation of stiffness of vocal folds based on phonovibrograms, phonetograms and software for overtones of the voice as usable tools.

There are still many options. Stiffness measured with phonovibrograms is a mechanical measure for determining flexure of the vocal folds during movement. Combined with overtones it might be used to determine the treatment effect in voice pathology. They are easier to use than air flow and phonetograms and quantitatively correct.

Keywords: Laryngeal disorders; Phonovibrograms; Phonetograms laryngo-stroboscopy

to capture 4000 or more images pr. second of the vocal area. Data are acquired with a high-speed camera recording in real-time during phonation of the vowel/a/. A rigid endoscope (90 optic, 9 mm diameter) is placed into the oropharynx coupled to a high-speed camera [4-6].

With the High Speed Endocam system there has been developed a software reproduction of the stiffness of single vocal fold movements with the Glottis Analysis programme (Wolf Ltd. HRES Endocam 5562 analytic system Richard Wolf GmbH, Pforzheimer Strasse 32, 75438 Knittlingen, Germany) [1,2] (Figures 1 and 2).

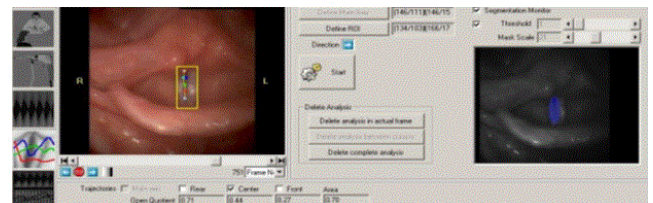


Figure 1 The figure shows the segmentation when the open quotients are calculated. The opening quotient is defined as the time the vocal folds are open divided by the time it is closed during intonation. The measures are calculated in front – center – rear area in three points– the quotients are usually a little smaller in front between the vocal folds [3].

Introduction

Methods of advances in diagnoses of laryngeal disorders include 1) high speed films with kymography, 2) overtone analysis up to 20000 Hz prospects of calculation of stiffness, phonovibrograms, phonetograms and 3) overtone software. Stroboscopy does not give a correct picture of the vocal folds' movements because it gives an average picture of 25 frames pr. Second. The vocal folds move 110-220 Hz during intonation in males and females on average. Therefore newer methods are necessary.

High Speed Films

High speed films are superior to clinical laryngo-stroboscopy in many areas of voice diagnostics. This explains why the diagnosis of nodules have been far too frequently used. An average picture of 25 frames per second seems not to be sufficient to diagnose nodules [1-3]. High speed films are able

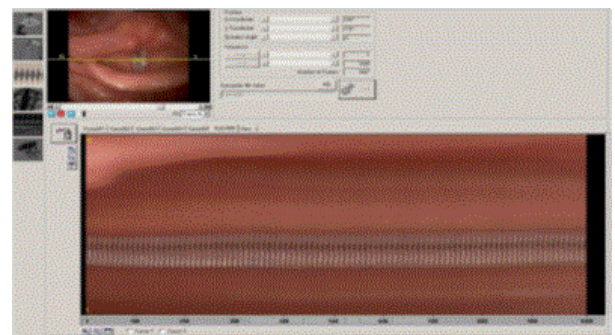


Figure 2 High speed films and kymography show single movements of the vocal folds from above here they are regular [3]. Kymography is a graphical representation of spatial position over time of the vocal folds seen from above.

High speed films and mean stiffness

Segmentation as seen in **Figure 3** the set-up for calculation of measurements of mean stiffness of the Glottal Area Wave form (GAW). The GAW is derived from high speed films and describes the vocal fold movements during intonation. GAW curves show how the area between the vocal folds increase and decrease. Stiffness is one of many measures that can be calculated from the data from the GAW curves.

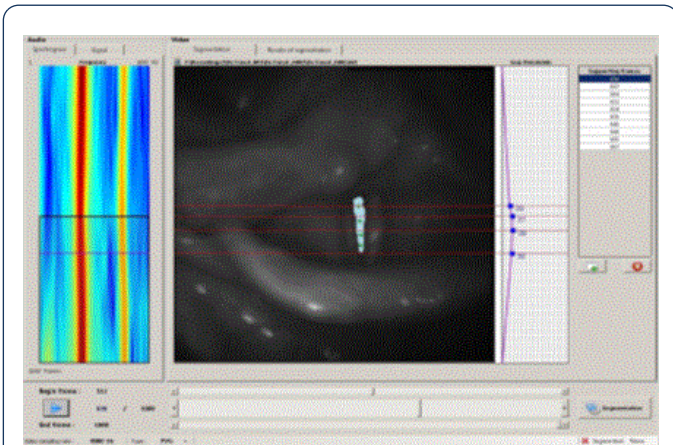


Figure 3 The set-up for calculation of measurements of mean stiffness of the Glottal Area Wave form (GAW). The GAW is derived from high speed films and describes the vocal fold movements during intonation at one point. Stiffness is one of many measures derived from the GAW.

The formula for stiffness

$$Stiffness = \frac{\max_t \subset T_i (s(t))}{A_i}$$

Where T_i is the duration of i th cycle in milliseconds (ms), A_i is the dynamic range (max-min) for i th cycle and $s(t)$ is the magnitude of the 1st derivative of considered signal for i th cycle ($t \subset T_i$) [2]. This formula has been used to compare normality with pathology of vocal folds [3].

Difference in stiffness

A difference in stiffness of the vocal folds single movements is measured comparing trained and non-trained voice users. The objective in a study was to evaluate the method based on software reproduction of the vocal fold movements, that is included in Glottis Analysis Tools used together with high speed films [4].

Trajectories

Trajectories are like kymograms. The diagram in **Figure 4** shows the vocal cords in a 50% distance from the posterior border (therefore called [Traj-50%]). The trajectory curves uses data derived from high speed films and shows the distance between the vocal folds at the 50% distance from the posterior border.

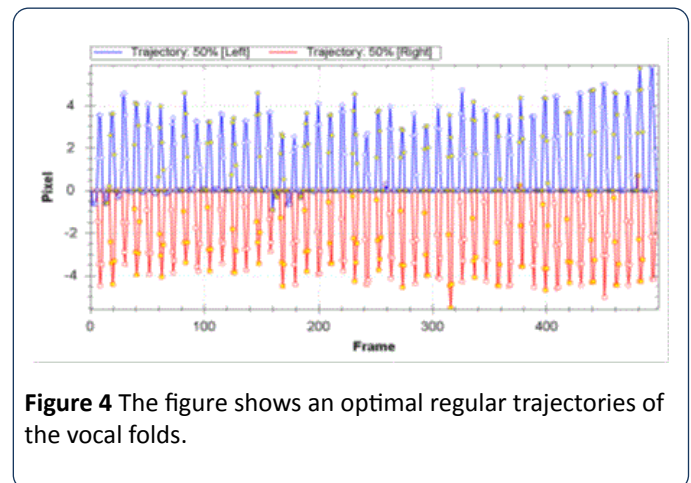


Figure 4 The figure shows an optimal regular trajectories of the vocal folds.

Trajectories of a 59 years old male is presented with acute laryngitis in **Figure 5**.

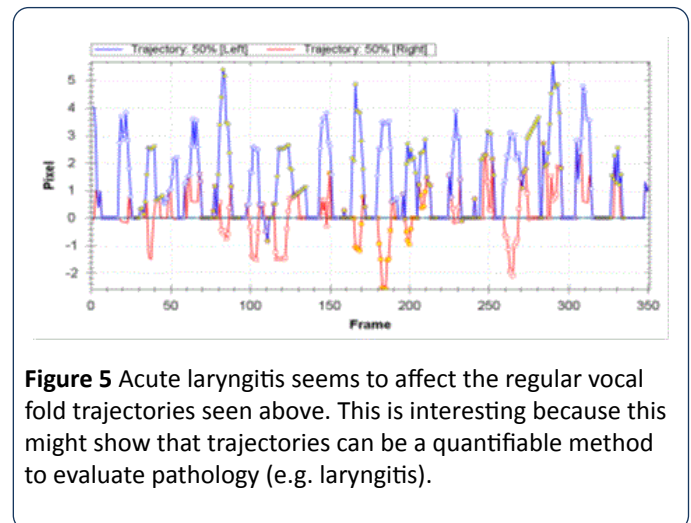


Figure 5 Acute laryngitis seems to affect the regular vocal fold trajectories seen above. This is interesting because this might show that trajectories can be a quantifiable method to evaluate pathology (e.g. laryngitis).

High speed films and phonovibrograms

The results of the segmentation of single vocal folds movement are shown in **Figures 6 and 7**. The Glottal Area Wave form (GAW) are shown with frames on the horizontal axis and pixel on the vertical axis [5].

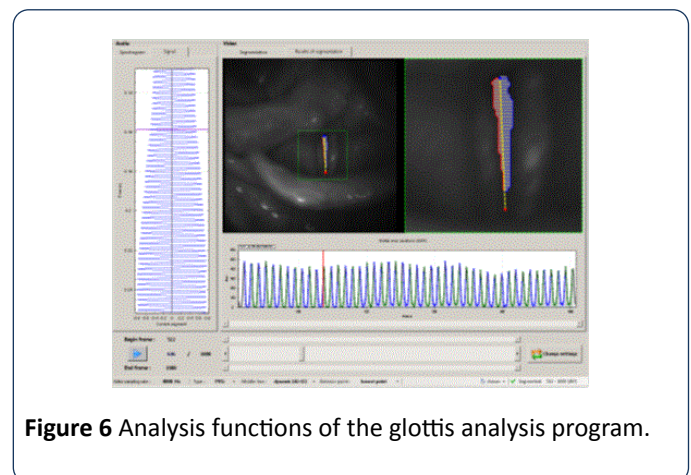


Figure 6 Analysis functions of the glottis analysis program.

Figures 6 and 7 shows the analysis functions of the Glottis Analysis Program [2]. The single movements presenting the area between the vocal Folds of the phonovibrogram of a optimally functioning female voice as defined in the software [2].

Irregularity of the single area measurements are seen of a 59 years old male with acute laryngitis in Figure 7.

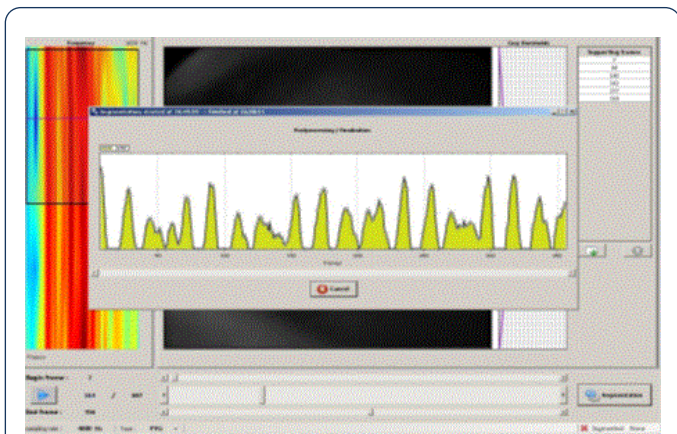


Figure 7 Irregularity of the single area measurements are seen of a 59 years old male with acute laryngitis.

There is a big difference to Figure 8. Single movements are irregular. This calculation is used statistically in the following tables.

Phonovibrogram of an optimally functioning female voice, showing the regularity of single movements of the right and left vocal folds (Figure 9).

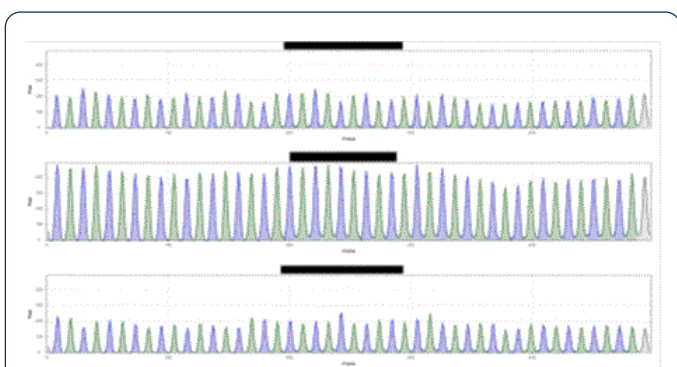


Figure 8 Glottal Area Waveform cycles of an optimally functioning female voice, right and left vocal fold, as well as area variation between the vocal folds in the middle.

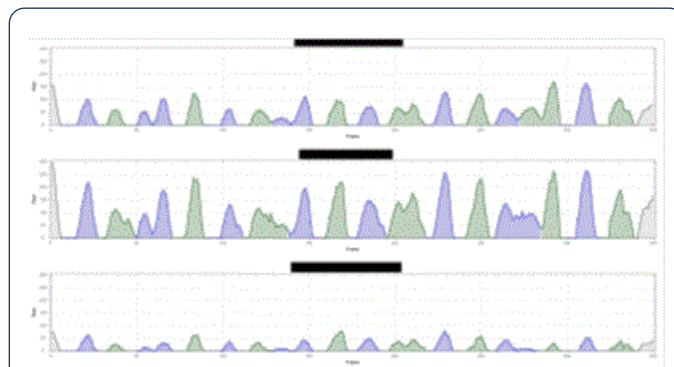


Figure 9 Glottal Area Waveform cycles of a 59 years old male with acute laryngitis (right and left vocal folds and area variation of vocal folds during intonation in the middle).

Phonovibrogram with single movements of the right and left vocal cord of a 59 years old male with dysphonia due to a heavy acute laryngitis (Figure 10 and 11).

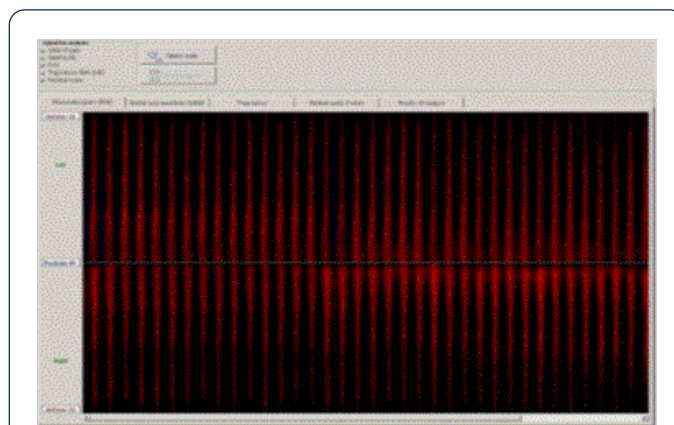


Figure 10 Phonovibrogram of an optimally functioning female voice, showing the regularity of single movements of the right and left vocal folds [4].

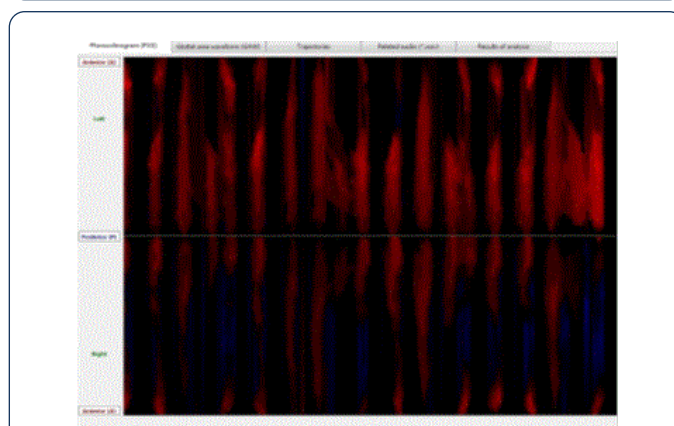


Figure 11 Phonovibrogram with single movements of the right and left vocal cord of a 59 years old male with dysphonia due to a heavy acute laryngitis [4].

Calculated measures for the signals of glottal area waveform and glottal trajectories

Figure 12 shows the huge variation of the stiffness of the 16 movements of the vocal folds in the patients with laryngitis (red dotted line) compared with the small variations of the 48 movements of the optimally functioning female voice (Tables 1 and 2).

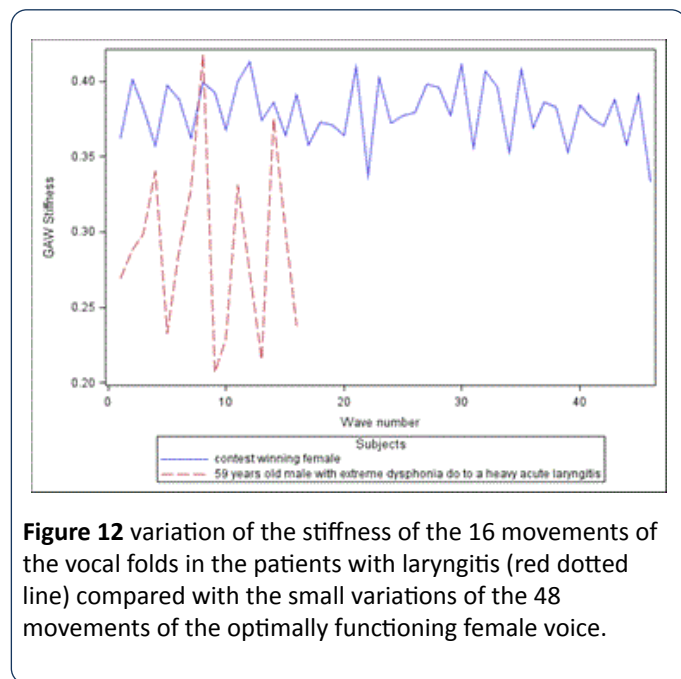


Figure 12 variation of the stiffness of the 16 movements of the vocal folds in the patients with laryngitis (red dotted line) compared with the small variations of the 48 movements of the optimally functioning female voice.

Table 1 48 movements of the vocal folds of an optimally functioning female voice. Statistical calculations are presented for the stiffness based on Glottal Area Waveform (GAW) – Mean, standard deviation, minimum and maximum stiffness, we also present the stiffness for the left and the right vocal fold as well as the stiffness based on trajectories.

			(Mean)	(Std)	(Min)	(Max)
Stiffness	(GAW)		0,38	0,024	0,333	0,413
Stiffness	(GAW)	(Left)	0,391	0,024	0,338	0,432
Stiffness	(GAW)	(Right)	0,395	0,024	0,352	0,451
Stiffness	(Traj-50%)	(Left)	0,483	0,043	0,371	0,625
Stiffness	(Traj-50%)	(Right)	0,486	0,029	0,392	0,513

Table 2 16 movements of the vocal folds from a 59 years male with extreme dysphonia due to a heavy acute laryngitis: Statistical calculations are presented for the stiffness based on Glottal Area Waveform (GAW) – Mean, standard deviation, minimum and maximum stiffness, we also present the stiffness for the left and the right vocal fold as well as the stiffness based on trajectories.

			(Mean)	(Std)	(Min)	(Max)
Stiffness	(GAW)		0,29	0,059	0,207	0,418
Stiffness	(GAW)	(Left)	0,313	0,056	0,232	0,444
Stiffness	(GAW)	(Right)	0,298	0,04	0,215	0,376
Stiffness	(Traj-50%)	(Left)	0,356	0,069	0,251	0,479
Stiffness	(Traj-50%)	(Right)	0,288	0,037	0,248	0,323

Statistical analysis of stiffness

In Table 3 a statistical comparison of stiffness measurements of the two subjects can be done under the assumption that all the measurements on the same subject follow the same Normal distribution. The hypothesis that the variation is the same for the two subjects can be tested in the likelihood ratio test, where the $-2\log$ likelihood difference is chi-square distributed with 1 degree of freedom, when it is assumed that the measurements have different means for the two subjects.

Table 3 A statistical comparison of stiffness measurements of the two subjects can be done under the assumption that all the measurements on the same subject follow the same Normal distribution.

Statistical model	-2 log likelihood	Likelihood ratio test statistic	P-value (chi-square distribution with 1 degree of freedom)
Subjects have different mean and variance	-261.2		
Subjects have different mean and same variance	-228.6	33.3	< 0.00001

Statistical conclusions of tables 1, 2 and 3

The statistical model shows that there is a statistical significant difference in the variation of the Glottal Area Waveform stiffness between the two subjects.

Table 4 shows Amplitude Symmetry is a formula used for quantifying how much the amplitude in a signal (in this case Trajectory curves) vary during intonation. The data analysis shows the female singer listed as "Singer observation", as well as an average of 12 hoarse patients from a voice data material listed as "Group average", hold up against the man with acute laryngitis (_A001(SegFr_7-356)) listed as "Observation".

The table shows an Amplitude-Symmetry deviation between the singer and the male with acute laryngitis. A significant

difference in Amplitude – Symmetry- Index is also seen ($p < 0.0001$).

Table 4 Amplitude Symmetry is a formula used for quantifying how much the amplitude in a signal (in this case Trajectory curves) vary during intonation.

Parameter	Source	Person	Laryngitis observation	Group average	Singer observation
Amplitude-Symmetry	[Traj-50%]	_A001(SegFr_7-356)	15796.53	1317.43	0.95
Amplitude-Symmetry-Index	[Traj-50%]	_A001(SegFr_7-356)	0.3	0.71	0.86

Segmentation curves for high speed film of dystonia patients

Calculations of open quotients in the front, center and rear parts of the vocal cords (**Figure 13**).

Visual irregularities illustrated due to a dystonia spasm – on movement curves of the vocal cords in front, center and rear, as well as area-, acoustical-, electroglottographical-, and kymographical curves [7].

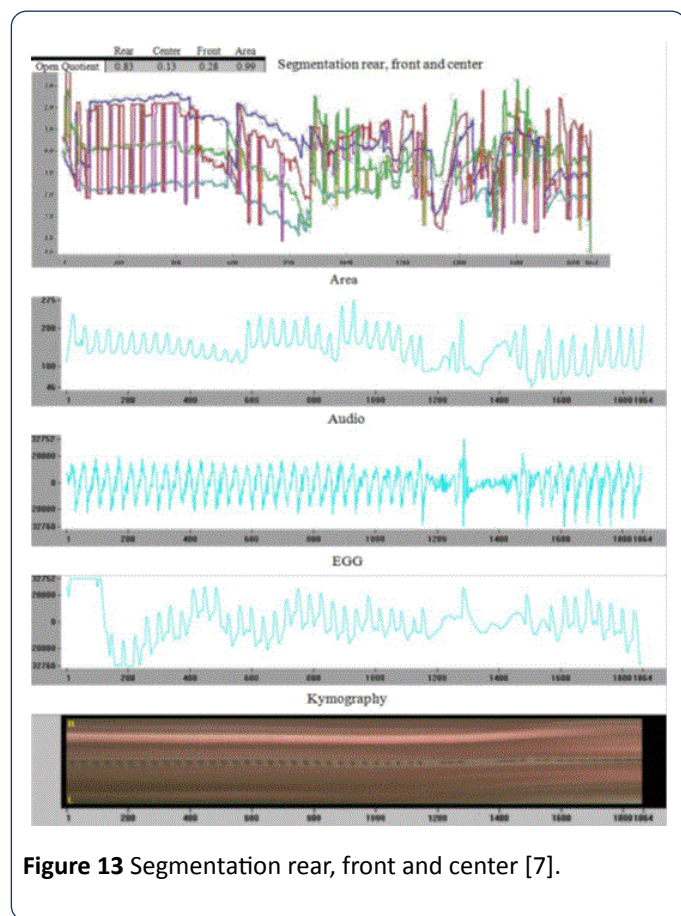


Figure 13 Segmentation rear, front and center [7].

Our first dystonia patient where high speed images were used to document changes, had total elimination of universal dystonia symptoms with local cortison inhaler in the larynx and the antihistamin fexofenadine referring to the research by Ludlow [8] (**Figure 14**). In addition high speed films showed regularity of laryngeal actions after the referred treatment. The elimination of dystonia in the larynx and in other parts of the body in some of these patients suggested a relationship between immunological deficiencies of the upper airways and the nature of dystonia, with relapses when the medication was terminated [7].



Figure 14 Patient where high speed images were used to document changes [7].

Overtone Analysis is Another Promising Software

High speed films were carried out combined with acoustical measures analyzed with " Sygyt Ltd." of a prospective cohort study of 12 normal persons, formants between 1000 – 5000 Hz and the variation in procent (**Figure 15**). It was shown that the normal variation of the formants found in the area was between 18% and 25% (**Table 5**). In pathology the formant variation but also the dispersion of harmonics is much bigger.

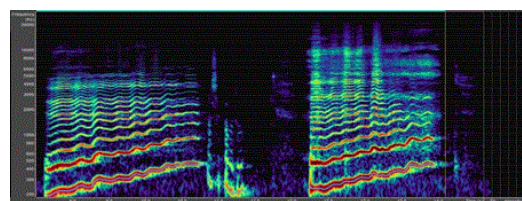


Figure 15 A Sygyt Software Ltd. presentation showing a normal female voice compared with a female voice of a singer where the upper register is weakened [3].

Table 5 Variation of 3 formants 1000-5000Hz [9].

Nr.	Name	Gender	Age	ms	F0 (Hz)	F0 (dB)	(Fa) (Hz)	(Fa) (dB)	Fx (Hz)	Fx (dB)	Fy (Hz)	Fy (dB)	Fz (Hz)	Fz (dB)
1	MP-A	K	75	520	327	64			1320	35	2312	34	3271	18
2	ACA-A	K	25	70	251	48			1261	33	2241	30	4025	28
3	LTC-A	K	40	1130	329	45			1401	28	2295	20	3357	9
4	KJH-A	K	47	850	142	15			1293	39	2328	24	3028	27
5	SM-A	K	24	900	307	38			1606	38	3206	25	4004	26
6	NBL-A	K	25	640	377	64			1131	23	2258	22	3411	14
7	AJ-A	M	24	120	216	56			1293	48	2371	40	3449	40
8	MSM-A	M	23	1060	158	38			1115	38	2549	29	3341	21
9	BHA-A	M	22	1210	266	47			1320	51	2904	30	4230	20
10	MO-A	M	28	440	211	49			1077	42	2373	28	4694	19
11	AH-A	M	16	430	139	42			1385	23	2500	28	3336	16
12	JJ-B	M	33	160	196	20			1040	12	1697	12	2204	19
Difference to sygyt sound analysis of 12 normal persons														
Coefficient of variation (cv)														
				mean					1513.5		2548.4		3834.8	
				change mean					243.3		128.9		305.7	
				std					270		632.7		923.4	
				cv					18%		25%		24%	

Phonetograms of Boys and Girls

Average phonetograms with standard deviation for a cohort of 4 sopranos and of 4 pubertal change groups (mutants) from the Leipzig Thomaner choir is shown in **Figure 16**. (The hormonal parameters were similar to those of the Copenhagen boys).

Average phonetograms and standard deviations for three choirboys (I–III) involved in a prospective longitudinal study in the 8th grade in a singing school are shown in **Figure 17**. The phonetograms before and after the mutational change of voice were compared. For test person I and II, only one phonetogram was made in mutation and before mutation respectively. For test person III, three phonetograms were measured before and three during the change of voice.

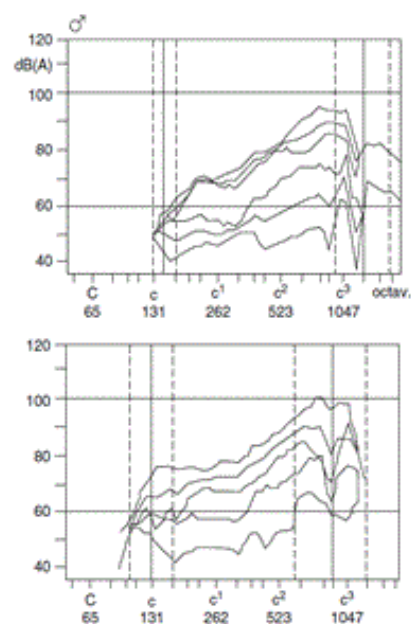


Figure 16 Average phonetograms with standard deviation for a cohort of 4 sopranos and of 4 pubertal change groups (mutants) from the Leipzig Thomaner choir [10].

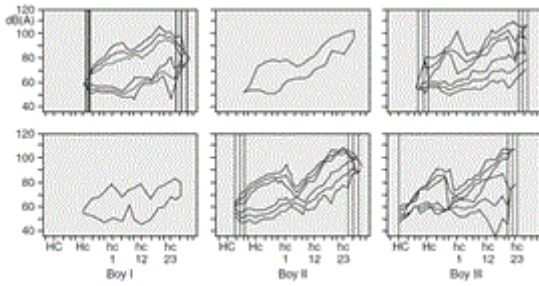


Figure 17 Average phonetograms and standard deviations for three choirboys (I-III) involved in a prospective longitudinal study in the 8th grade in a singing school [10].

Average phonetograms with standard deviation for boys and young men from a boys' choir at a Danish choir school, as a function of voice type are presented in **Figure 18**. (The voice type was determined by the singing teacher.) The abscissa is divided up into semitones, and the frequency in Hertz of each octave is indicated. The scale of the ordinate is dB(A).

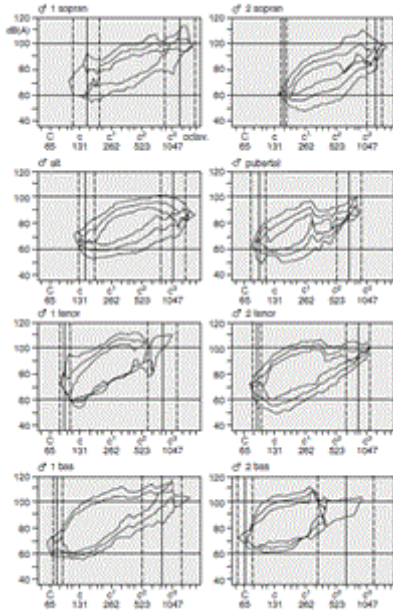


Figure 18 Average phonetograms with standard deviation for boys and young men from a boys' choir at a Danish choir school, as a function of voice type [10].

Average phonetograms with standard deviation for girls and young women from a girls' choir at a Danish choir school, as a function of voice type are presented in **Figure 19**. (The voice type was determined by the singing teacher.) The abscissa is divided up into semitones, and the frequency in Hertz of each octave is indicated. The scale of the ordinate is dB(A). One group could not be securely defined during puberty.

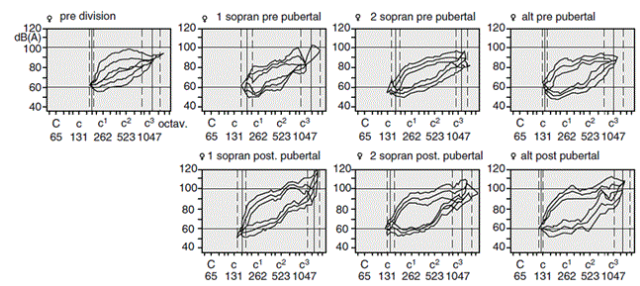


Figure 19 Average phonetograms with standard deviation for girls and young women from a girls' choir at a Danish choir school, as a function of voice type [10].

Dys-functional voices showing reduced phonetograms in brain damaged young people

A1-A2. 5 severely disturbed male voices (Phonetogram surface improves 70-115 half tones x dB). B1-B2. 5 moderate impaired male voices (Phonetogram surface improves 207-246 half tones x dB) [11] (**Figure 20 and Table 6**).

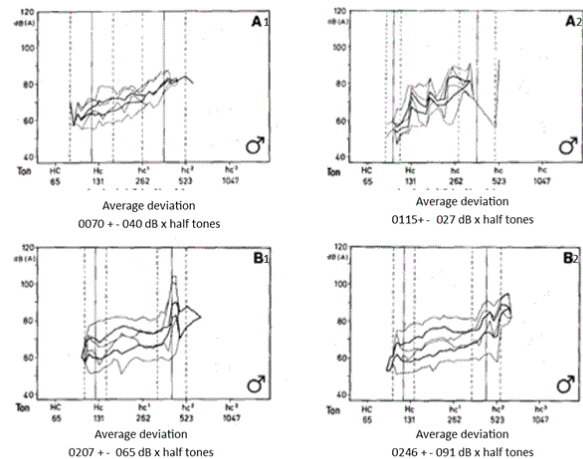


Figure 20 Brain-damaged patients before and after treatment. Phonetogram averages and standard deviation.

Flow Measurements have also been Tried

Table 6 Multivariate statistical analysis in 16 male brain injury (SAS Statistics).

	Average	SD	Correlation	Of interest
Age	35 years		14 (-.48)	15 (-.44)
Peakflow	7739 ml/s	1802	4 (.43)	5 (.47)
vital capacity	4052 ml	947	4 (.88)	10 (.70)
Maximal phonation time	3170 ml	989	5 (.48)	10 (.57)
Phonation	17 s	9	6 (-.47)	8 (-.69)
stability of the fundamental frequency	13.00%	9.9	11 (-.43)	
Stability of SPL	0.4dB	0.2	12 (-.42)	
Average air flow velocity			9 (.96)	11 (-.15)
Phonation quotient	275.8 ml/s	33		11 (-15)
Quotient of air consumption (average wind velocity / phonation quotient)	77.50%	10.10%	11 (.31)	
Phonetogram areal in half tones x dB	224	177	1 (.67)	12 (.49)
Maximal dynamics	19.5dB	5.4	15 (.60)	14 (.51)
lowest tone of phonegram (geometric average)	106Hz	18	14 (-.45)	
Half tones of phonetogrammes	24	8	15 (.95)	
highest ton of phonetogrammes	438 Hz	166		
(p < 0.05 über .51; P <0.01 über 0.60				

Discussion and Conclusion

Till now we have seen a difference between high quality voices and other voices with advanced measures and based on high speed film and overtone analysis as well as phonograms and air flow. We presented a quantified measure of the vocal fold stiffness calculated from individual vocal cycles and average measures during voice development related to hormones and in pathology of brain damaged patients and dystonia.

It is our impression that the system Glottis Analysis Tools stiffness calculations can be used clinically to differentiate between high and low quality voices as well as pathology.

In the future, high speed films including stiffness of phonovibrograms together with overtones might be used to

determine the treatment effect in voice pathology. It is easier to use than air flow and phonetograms. Still there might be different options dependent on development in equipment for clinical use.

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