Conference of optical imaging, therapeutics, and advanced technology in head and neck surgery and otolaryngology 8207C-319

New standard measures for clinical voice analysis include high speed films

Mette Pedersen and Kasper Munch
The Medical Centre, ear-nose-throat and voice clinic,
Østergade 18 Dk-1100 Copenhagen, Denmark.
e-mail to: m.f.pedersen@dadlnet.dk
website: www.mpedersen.org
SAS institute, Købmagergade 7-9, 1150 Copenhagen
www.sas.com

ABSTRACT

In the clinical work with patients in a medical voice clinic it is important to have a normal updated reference for the data used. Several new parameters have to be correlated to older traditional measures.
The older ones are stroboscopy, eventually coordinated with electroglottography (EGG), the Multi-Dimensional-Voice Program and airflow rates. Long Time Averaged Spectrograms (LTAS) and phonetograms (voice profiles) are calculating the range and dynamics of tones of the patients.
High-speed films, updated airflow measures as well as area calculations of phonotograms add information to the understanding of the glottis closure in single movements of the vocal cords.
A multivariate analysis was made to study the connection between the measures. This information can be used in many connections, also in the otolaryngological clinic.

1. INTRODUCTION

Advanced measures for voice analysis in patients are now-a-days not evidence based for clinical use, in randomised clinical trials as a basis for meta-analysis. Updated Cochrane reviews were made on voice disorders where no RCT was found (1-10). Evidence in voice research has been discussed by our group at several conferences, e.g. IFOS 2009 (11). The problem has to some extend been the lack of normal voice function values that can be used for voice related medical treatment of allergology, infections of the upper airways as well as reflux, neurological-, emotional, environmental and genetics voice disorders. There is now established an updated approach frame of measurement references in a Danish material of amateur student singers for use in our clinic for further research.

In the clinical situation diagnoses of voice disorders **will vary,** depending on the apparatus, and also on the cooperation between medical doctors, voice pathologists, engineers and phoneticians. The groups are communicating with gastroenterologists, allergologists, experts of microbiology of infections, immunology and genetics as well as neurology and surroundings. Their work is at best coordinated with statisticians and used by teachers in singing and other voice related scenario of voice teaching.

2. METHODS

18 healthy amateur female singers and 12 healthy amateur male singers between 20 and 40 years of age were analysed in a stratified cohort study.

2.1 Multi-Dimensional-Voice-Program

TheMulti-Dimensional-Voice-Program combined with video stroboscopy (MDVP) by the firms Key Elemetrics and Laryngograph were used :

A sustained note 'ah' and reading of a standard sentence: -' the blue spot is on the key again', and the story: 'the Northern wind and the Sun', respectively. Jitter and shimmer were measured for the sustained notes. Mean fundamental frequency, frequency- and intensity- variation percent were measured for the sentence. For the firm Key Elemetrics also harmonics to noise ratio and degree of voicelessness were measured, and for the firm Laryngograph, also glottal closed phase (Qx%) of the electroglottogram (EGG), and cohesion factor (irregularity)% of the fundamental frequency and the EGG.

Rutine measures were made of phonation time, maximal and minimal tone ranges.

2.2 Long term average spectrograms (LTAS)

LTAS measurements up to 11.000 Hz were made with Laryngograph equipment. Calculations of harmonics were made.

2.3 Phonetograms

Phonetograms included calculations of the lowest note, the highest note, maximal dynamics and calculation of area of voicing in semitones times decibels (dB(A)).

3.3 Airflow measurements

Airflow measurements were made for sustained notes and consonant/vowels (Aerophone and Aerophone II by F J Electronics and Key Elemetrics) lung volume, peak flow, mean flow rate, phonation times, as well as the parameters of adduction/abduction rates pr second as an indication of the vocal fold movements pr second, and target flow rate parameters of the mid 50% of the sampled values measured during the loudest 6dB.

3.4 High speed digital imaging (HSDI)

HSDI based on the apparatuses by the firm Wolf, Germany, included qualitative measurements of kymography, acoustical curve and FFT up to 2000Hz. Quantitatively, the opening phase between the vocal cords in front, middle and rear parts and area opening was made based on segmentation calculation in % between the vocal cords. Supplementary EGG were made on line, but till now no on line quantitative measures can be presented of comparison of the EGG and the acoustical curves.

3.5 Standard deviations

Standard deviations and ranges were made. Multivariate correlations by pair were made and significance probabilities more than 0,5 were included. One way analysis of power (dB) was made by gender with summery of fit. A model for spectrograms of polynomial fit degrees = 5 was used for the variety fit of power (dB) by frequency (Hz) for sustained notes. For spectrograms of reading of a text the polynomial fit degree = 6 was used for bit variety fit of power (dB) by frequency (Hz). The statistics were made in a frequency area from 0-11.000 Hz and in 3 sub groups of frequency of 200-800 Hz, 2300-2700 Hz and 9.500-11.000 Hz. (SAS institute program, JMP 7 used in the clinic).

3. RESULTS

The 18 female and 12 male amateur singers had normal video stroboscopies:

The mucosa representing normality and no reactions of e.g. infections, allergies and others.

The arytenoid regions without any oedema or other reactions e.g. related to the swallowing process.

3.1 Standard set-up for medical, clinical use

3.1.1 Table 1: Airflow

The mean flow rate, vital capacity, peak flow and phonation times in 12 normal Danish males and 18 females between 20-40 years of age, on a sustained tone. The average mean flow rate showed a difference between males (204 ml pr. second) and females (178 ml pr. second).

	Average	Range		S.D.
		Lowest	Highest	
MEAN FLOW RATE ml pr second				
Male	0,204	0,031	0,527	
Female	0,178	0,106	0,318	
VITAL CAPACITY				
Male	5,138	3,460	8,876	
Female	3,723	2,615	4,219	
PEAKFLOW litres pr second				
Male	10,993	8,880	19,920	
Female	7,366	5,560	8,840	
Phonation time (in Aerophone)				
Male	15,0	5,6	23,4	4,6
Female	18,0	9,0	26,8	4,9

Table 1

3.1.2 Table 2: Jitter and Shimmer

on sustained notes for 4 seconds, by MDVP and Laryngograph Ltd. The results of the two firms were correlated.

	Average	Range	
		Lowest	Highest
Average Fx (Sust.note)			
Male	140,048	116,040	169,400
Female	272,371	206,620	308,600
Jitter (Sust.note)			
Male	0,320	0,200	1,080
Female	0,541	0,140	2,080
Shimmer (Sust.note)			
Male	7,116	3,090	17,540
Female	8,227	2,010	18,690

Table 2

3.1.3 Table 3: Frequency and intensity variation during reading

The results in table 1 were compared with a measure of frequency and intensity variation in percent during reading of a standard text, the Northern wind and the Sun.

	Average	Range	
		Lowest	Highest
Average Fx (Speech)			
Male	127,898	106,560	171,050
Female	227,405	198,260	262,700
Irregularity of frequenzy (Hz,Speech)			
Male	5,469	3,040	6,770
Female	5,448	2,620	7,550
Irregularity of intensity (dB,Speech)			
Male	18,047	13,950	20,900
Female	13,389	11,460	17,030

Table 3

3.1.4 Table 4: Harmonics to noise and degree of voicelessness

Measures were made with the MDVP program, ranges and standard deviations.

	Average	Range		S.D.
		Lowest	Highest	
Harmonics to noise ratio				
Male	0,40	0,23	0,91	0,18
Female	0,37	0,21	0,860	0,220
Degree of voiceless ness				
Male	56,0	22,640	91,340	13,600
Female	66,0	25,260	86,900	18,100

Table 4

Table 5: Laryngographic (EEG) measured closed phases (Qx%)
of the vocal cords on sustained tones /ah/ in on a comfortable tone in the speaking area for 4 seconds and during reading of the standard text.

	Average	Range	
		Lowest	Highest
Average Qx (Sust. note)			
Male	47,944	39,9	63,33
Female	46,032	37,65	60,94
Average Qx (Speech)			
Male	51,248	46,07	58,55
Female	49,239	39,99	57,46

Table 5

3.1.5 Table 6: Cohesion factors of irregularity percents

With the Laryngograph Ltd. set-up. A division is made for a sustained tone /ah/ on a comfortable speaking level and during the reading of a standard text, and for fundamental frequency (Fx irregularity%) and EEG closed quotient percents (Qx irregularity%) .
No significant difference was found for fundamental frequency, frequency and intensity variation in reading and for a sustained note for the firms Key Elemetric and Laryngograph. The use of the term jitter and shimmer in reading of a standard text should instead in the future be replaced by frequency and intensity variation during reading, in percent.

	Average	Range	
		Lowest	Highest
Cohesion factor % Fx (Sust. Note)			
Male	0,788	0,220	4,060
Female	0,415	0,090	1,000
Cohesion factor % Fx (Speech)			
Male	19,518	6,410	71,490
Female	8,525	7,360	14,890
Cohesion factor % Qx (Sust. Note)			
Male	7,987	0,400	31,030
Female	25,218	0,460	60,730
Cohesion factor % Qx (Speech)			
Male	40,209	28,350	82,010
Female	33,211	3,790	63,770

Table 6

3.2 New set- up for medical, clinical use includes

3.2.1 Figure 1, 2: Long Time Average Spectrograms (LTAS) sustained tones

The LTAS results had significant different results of harmonics between males and females. The differences were found specifically at the areas 200-800 Hz, 2300-2700 and 9500-11000 Hz.
The sustained tones for 4 seconds of both males and females are presented in polynomial fit degree=5 areas are marked from 200-800, 2300-2700 and also 9500-11000.

With one way analysis of power by gender, a difference was found between resonance power, better for males at the area 200-800 Hz (40 versus 34 dB). At the area between 2300-2700 (23 versus 20 dB) the resonance power was also better for males,

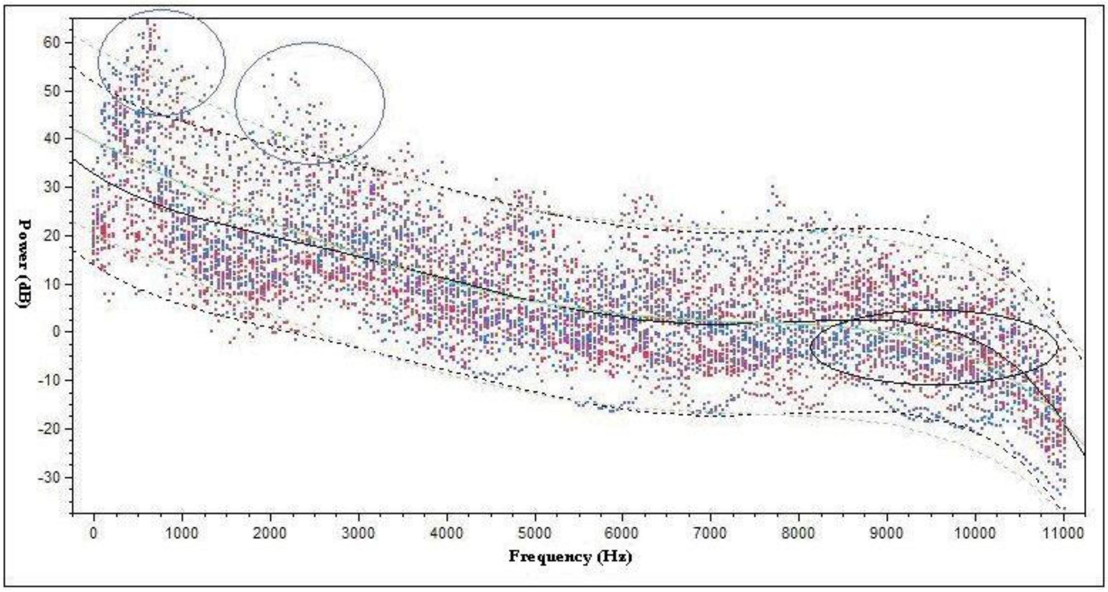


Figure 1

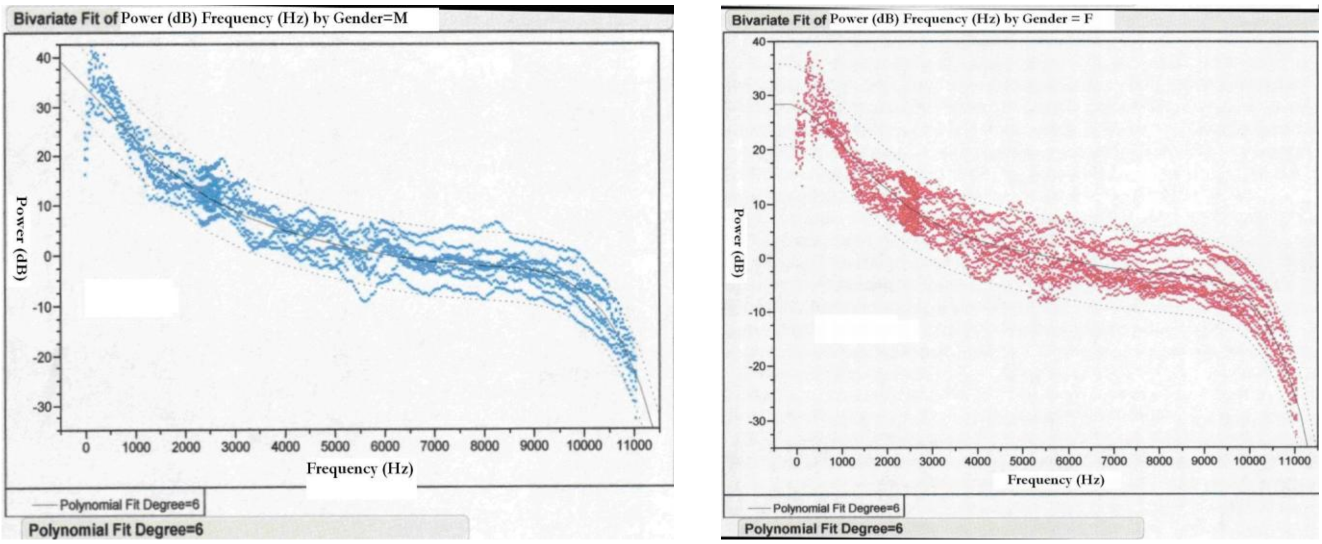
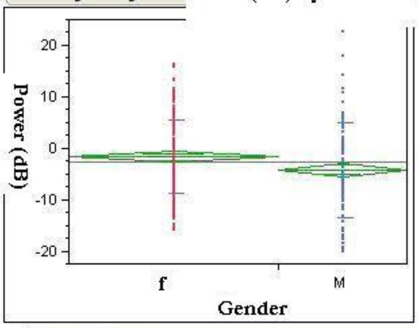


Figure 2

3.2.2 Figure 3: Statistics showing LTAS calculations of gender differences between 9500 and 11000 Hz
At 9500-11000 Hz there was a slightly better result of intensity for females. Measurements from 9500-11000 Hz were based on a polynomial fit degree=5 of sustained tones

Oneway Analysis of Power (dB) by Gender



Oneway Anova

Summary of Fit

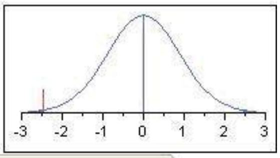
Rsquare	0,022147
Adj Rsquare	0,019321
Root Mean Square Error	7,990813
Mean of Response	-2,70526
Observations (or Sum Wgts)	348

t Test

M F

Assuming equal variances

Difference	-2,4713	t Ratio	-2,79936
Std Err Dif	0,8828	DF	346
Upper CL Dif	-0,7349	Prob > |t|	0,0054*
Lower CL Dif	-4,2076	Prob > t	0,9973
Confidence	0,95	Prob < t	0,0027*



Analysis of Variance

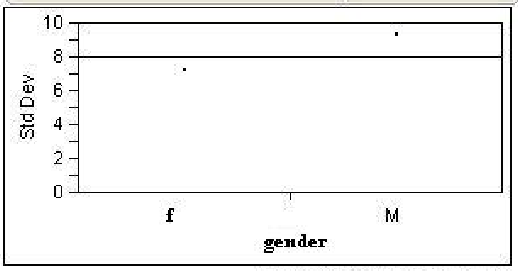
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Gender	1	500,378	500,378	7,8364	0,0054*
Error	346	22093,171	63,853		
C. Total	347	22593,549			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
f	216	-1,7679	0,54371	-2,837	-0,698
M	132	-4,2392	0,69551	-5,607	-2,871

Std Error uses a pooled estimate of error variance

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
f	216	7,136256	6,043597	6,034722
M	132	9,223289	7,513611	7,457348

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	13,2963	1	346	0,0003*
Brown-Forsythe	8,0971	1	346	0,0047*
Levene	9,0730	1	346	0,0028*
Bartlett	11,0192	1	.	0,0009*
F Test 2-sided	1,6704	131	215	0,0009*

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
6,9383	1	225,96	0,0090*

t Test

2,6341

3.2.3 Table 7: Phonetograms

The calculated results were presented for phonetograms of the lowest tones, 87 Hz for males and 160 for females respectively, the highest tones, 716 and 1084 Hz, the maximal dynamic area 32 dB and 37 dB and the total area in semitones times decibels 714 for males and 822 for females. Ranges were also presented as well as standard deviations.

	Average	Range		S.D
		Lowest	Highest	
Lowest tone				
Male	87	73,4	98	31
Female	160	131	220	33
Highest tone				
Male	716	622	880	154,8
Female	1084	1568	1245	204,3
Maximal dynamic range				
Male	32	24	57	8,4
Female	37	20	41	9,01
Total area in semitones times decibels				
Male	714	406	1054	202
Female	822	432	1047	214

Table 7

3.2.4 Table 8: Airflow

Some of the important airflow parameters based on the Aerophone II by FJ Electronics included abduction/adduction rate of the vocal cords in movements per second measured during voicing of a?a?a?a? as fast as possible. Another new measure is the target air flow rate: the average airflow rate of the mid 50% of the sampled flow values, measured during the loudest 6 db of the SPL curve, and real air pressure in cm water. The target flow rate was 0.24 in males and 0.17 ml per second in females. The adduction / abduction rate in males 8, 41 and in females 7.59, the real air pressure in males 8, 30 and in females 7, 83 cm H2O. Ranges and standard deviations were given.

	Average	Range		S.D
		Highest	Lowest	
Adduction –Abduction rate				
Male	8,41	11,87	5,64	1,70
Female	7,59	10,37	5,1	1,56
Target flow rate (l/sec)				
Male	0,24	0,45	0,17	0,117
Female	0,17	0,21	0,08	0,05
Target SPL (dB)				
Male	82,00	89,26	77,28	3,80
Female	79,43	87,12	70,86	6,36
Real air pressure (cmH2O)				
Male	8,30	12,22	5,15	2,23
Female	7,83	9,96	4,034	1,64

Table 8

3.2.5 Table 9: High speed films

The open quotients of the high-speed films were calculated in % on segmentation, in front, centre and rear as well as the area of the general open phase, using the equipment and software from the firm Wolf. In front the open quotients were 0, 45 and 0, 48 in males and females respectively, in the centre 0, 51 and 0, 58 and rear 0, 59 and 0, 48. The open areas between the vocal cords were in males 0, 60 and in females 0, 68. Ranges and standard deviations were given.

	Average	Range		S.D.
		Lowest	Highest	
Open quotient front				
Male	0,45	0,14	0,92	0,32
Female	0,48	0,37	1,60	0,49
Open quotient centre				
Male	0,51	0,09	1,0	0,27
Female	0,58	0,12	1,0	0,29
Open quotient rear				
Male	0,59	0,07	0,99	0,32
Female	0,48	0,00	1,00	0,31
Area between vocal cords				
Male	0,60	0,04	1,0	0,43
Female	0,68	0,13	1,0	0,30

Table 9

3.3 Statistics related to the Multivariate Analysis with SAS JMP 7 statistical program

A multivariate statistics made with SAS JMP statistical calculation showed many correlations between the new measures. The clinical value of the results is that it documents the voicing as a wind instrument, to be used in the clinical setting with patients with especially mucosal and neurological disorders, where the airflow regulation is compromised. 40 significant measures were calculated in this study of normal clients.

3.3.1 High speed films (HS) e.g.:

The multivariate analysis showed in this normal material

r .8130, and p 0.0001 for HS open quotient front versus HS open quotient centre.,

r .6748, and p 0,0021 for HS open quotient front versus HS area between the vocal cords, r .7574, and p 0,0003 for HS open quotient centre versus HS area between the vocal cords. A correlation of r .4567,and p 0,0568 was found between the HS area between the vocal cord and the closed phase on the electroglottogram (EGG, Qx%) during reading of a standard text.

3.3.2 Phonetograms e.g.:

r -.6524, and p <0,0001 for the maximal dynamic range (dB) versus the phonetograms area in semitones times decibels

r -.6123, and p 0,0003 for the lowest tone (Hz) versus peak flow rate in litres/sec.

r -.5800, and p 0,0008 for the lowest tone (Hz) versus the vital capacity in litres.

r -.5743, and p 0,0017 for the highest frequency (Hz) versus the target flow rate in litres/sec.

r .3677, and p 0,0456 for the dynamic range in dB of the phonetograms versus the maximum phonation time in sec.

3.3.3 Aerophone II e.g.:

r .8461, and p< 0,0001 for peak flow (litre/seconds) versus vital capacity (litre)

r .5065, and p 0,0060 for max phonation (seconds) time versus mean air flow rate (litre/sec)

r .4594, and p 0,0107 for ad/abduction rate (cps) versus phonation quotient (litre/sec)

r .5027, and p 0,0123 for target flow rate (litre/second) versus target resistance

r .-3675, and p 0,0543 for ad/abduction rate (cps) versus mean flow rate (litre/sec)

4. DISCUSSION

Normal materials of voice measurement vary with age and local language as well as with cultural level of language. We have earlier measured the fundamental frequency and phonetograms up to 18-19 years of age compared with hormonal development and secondary gender characteristics. The same approach will be made again for the aging of the voice. The suggested air flow measures and high speed filming will make the results even more up-dated for comparison with pathology.

LTAS averaged from 1-11.000 Hz was made in our large materials on sustained tone and in reading of a standard text in 12 normal males and 18 females aged 20-40 years shows significant differences between the genders. Single plots though give no information about the quality of the voice, usable in pathology related e.g. to allergy, infections of the upper airways, reflux and many other disorders, except in extreme cases.

The open quotient in high speed films is interesting, variations give information as a basis for treatment e.g. of posterior laryngitis as seen in laryngo-pharyngeal reflux, development of voice with changing registers and neurological disorders, e.g. dystonia patients often have reduced open phases and irregular patterns. Various voices related technical singing problems are illustrated with the closure in front, centre and rear part of the vocal cords. In our set up combined on line acoustical, electroglottographical (EGG) and kymographical signals shows us where the disorder is located.

We have presented statistical relations for the new measures of high speed films, LTAS, phonotograms area and the airflow related parameters. The high correlations in the SAS statistical program indicate that these measurements must be used much more in the future. This is a promising cue to further understanding of the voice as a wind instrument. The documentation aspects of treating allergy, infection, reflux, mucosal and neurological disorders at the laryngeal level certainly have taken a step forward with air flow measures, combined with qualitative on line- and quantitative high speed films (12) . To document pathology, measures were made, hopefully even more exact,to present a significantly related frame of normality for perceptual, physiological, acoustical and air flow measures of speech (13,14,15,16,17).

5. CONCLUSION

The medical clinical tools: high speed films were evaluated in 30 amateur singers and the (normal) results were correlated with other parameters measured at the same time in a multivariate statistical analysis with SAS JMP statistics. Measures of air function show that airflow analyses could be used much more in the future since the significant values related to voice were high.

The aspect of air pressure measurement is promising for clinical trials of treatment effect of upper airway disorders. For high speed films the quantitative measurements must be further developed. Till now, the measures presented in the MDVP and Laryngograph set-ups including phonetography get heavily better scientific perspectives of accuracy with high speed films and updated airflow measures for measurement of voice pathology

6. ACKNOWLEDGEMENTS

Thanks to the students in the clinic especially Anders Jønsson, Christina Heltoft and Sanila Mahmood.

7. REFERENCES

[1] Cochrane Library, Wiley publishing Oxford UK. http://interscience.wiley.com/

[2] Pedersen M, McGlashan J (2007). “Surgical versus non-surgical interventions for vocal cord nodules”. Cochrane Review Update in The Cochrane Library Oxford, Wiley publishing UK. Issue 1

[3] Hopkins C, Yousaf U, Pedersen M (2006). “Acid Reflux Treatment for Hoarseness [Review]” January 2006 in The Cochrane Library Oxford, Wiley publishing UK. Issue 1.

[4] Pedersen M, Beranova A, Moeller S (2004). “Dysphonia: Medical treatment versus a medical voice hygiene advice approach” European Archives of Otorhinolaryngology, Springer Verlag Germany (electronic version 2003) 261; 6:312-5.

[5] Pedersen M (2008). “Medical treatment versus a medical voice hygiene advice approach” Slideworld.org, USA: http://www.slideworld.org/ViewSlides.aspx?URL=4884 (date last viewed 12/1/08).

[6] Pedersen M (2004). “Interactions between basic and clinical research. International Conference Voice Physiology and Biomechanics report.” Marseille France; pages 137-143.

[7] Pedersen M, Yousaf U (2006). “Videostroboscopic expert evaluation of the larynx with running objective voice measurement at the same time gives more secure results than videos alone” Congress report. The 5th International Conference on Voice Physiology and Biomechanics Japan; pages 110-3.

[8] Pedersen M, Munck K (2007). “A prospective case-control study of jitter%, shimmer% and Qx%, and glottis closure cohesion factor (Spead by Laryngograph Ltd.) and Long Time Average Spectra.” Congress report Models and analysis of vocal emissions for biomedical applications (MAVEBA) Italy; pages 60-4.

[9] Pedersen M (2007). “Evidence based voice assessment. Instruction course.” European Archives of Oto-Rhino-Laryngology and Head and Neck EUFOS, Vienna Austria ; 264: Supplement S10 HIC 21.

[10] Pedersen M (2007). “Coughing and voice disorders in rhinitis and asthma the role of allergy and medication.” XIIth Congress of the International Rhinological Society, Venice Italy 2007 Roundtable. (By invitation)

[11] Pedersen M (1997). “Biological development and the normal voice in puberty.” Thesis. University of Oulu Finland and Gentofte University Hospital, (director prof. M.Tos) ENT Dpt, Denmark. Book (2008): The normal development of voice in childhood, *Springer*, Germany.

[12] Loschceller J, Voigt D, Döllinger M, Eysholdt U (2008). ”Phonovibrograms: Fingerprints of vocal fold vibrations.” Second COST action 2103 Workshop, abstract book: Advanced voice function assessment. Aachen, Germany.

[13] Loebach JL, Bent T (2008). “Multiple routes to the perceptual learning of speech.” J. Acoust. Soc. Am. 124: 552-561.

[14] Watson PJ, Munson B (2008). “Parkinson´s disease and the effect of lexical factors on vowel articulation.” J. Acoust..Soc. Am. 124: EL 291-295.

[15] Ohala JJ. (1974). “A mathematical model of speech aerodynamics.” Speech Seminar Stockholm Sweden. Aug.1-3.

[16] Mihaescu M, Khosla S, Gutmark E. (2008). “Unsteady laryngeal airflow simulations: An analysis of the generated intraglottal vertical structures.” J. Acoust.. Soc. Am 124: 2579-80.

[17] Izdebski I, (2011) “Clinical Voice Assessment: The role & value of the phonatory function studies” In Current Diagnosis and Treatment. Otolaryngology Head and Neck Surgery. Third edition. Ed. Lalwani AK, publisher: Mc Graw Hill Medical: 135-448