

# Development of voice in childhood

## PART 1

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## **1.1. Introduction**

During the work as a laryngologist for 10 years in the Copenhagen singing school which was developed by Mogens Wøldike, questions about the biological development of the pubertal voice often arose. The most important question was always: does a boy lose the high notes of his voice due to infection, allergy, misuse or puberty.

Because these causes of voice function failure interfere with each other, it was difficult to give an exact answer. Still it is the conviction that the main difficulty lies in judging the loss of high notes due to puberty.

Measuring the voice is necessary for youngsters to understand the pubertal development of their voices. Here, stroboscopy alone seemed insufficient because registration of pubertal pitch and loudness changes were not taken into account. For this reason the fundamental frequency in running speech in a reading situation was computed. In addition voice range profiles / phonetography in phoniatics, a corresponding measurement to audiometry in audiology, allow a more exact definition of the pubertal voice.

The mean fundamental frequency measurement in running speech (F0) is an international topic of discussion. The electroglottographic method has been preferred because it is simple and well defined in a reading situation. The exact objective measurement of voice was a basis for discussion with paediatricians and researchers of androgens and estrogens, thereby raising their interest in voice research as a basis for further understanding of the effect of hormones on voice.

## **1.2. Review of the Literature**

### **1.2.1. Voice range profiles**

#### **1.2.1.1. Voice range profiles /phonetography, the method**

In the first years of early phoniatics, careful studies of semitone ranges of normal school child were carried out by Flatau and Gutzman (1905). A survey of research on children's voices was proposed at the international conference for logopedics and phoniatics in Copenhagen in 1936 and later carried out by Weiss.

The survey has a time span of 4000 years and focuses almost exclusively on boys' and eunuchs' voices. The last eunuch died in 1922 (Siegel 1994). The average age of the mutation was recognized to be around 14.5 years, with one octave of the fundamental frequency lowering in boys, and in girls 1/3 octave (Weiss 1950).

Many others have reached the same conclusions (e.g. Frank and Sparber 1970, Wendler and Seidner 1987). Blatt (1983) discusses all aspects of educating voices in puberty. In 1984 Komyama et al. analyzed normal children during puberty, but unfortunately without comparison to other phenomena of puberty and only with a lower borderline of 60 dB(A). It is possible to further lower the sound level measurements, therefore their results are not comparable to our line of 30-40 dB (A).

Meuser and Nieschlag (1977) found voice categories (i.e., bass - baritone - tenor) in adult men to be related to the concentration of serum testosterone. Large and Iwata found differences in formants related to voice categories in adults as early as in 1972. We also found that it is necessary to differentiate between voice categories, if an exact evaluation of the pubertal development of the voice is to be obtained.

Since we started our examinations, Klingholz et al. (1989) in Tölzer Knabenchor have studied phonetograms with an automatic classification of the sopranos and altos. Konzelmann et al. (1989) have examined the phonetograms and singing formants in singers and non-singers. Grit Bühring (1990) had a survey of literature in her dissertation in Leipzig and tried to set the circumscripts of phonetograms on mathematic formulas to compare measurements between the Copenhagen boys choir and the most famous Thomaner boys choir which was used by Johan Sebastian Bach, in Leipzig - in Germany. .

Behrendt (1989) has followed a fistula register in phonetograms into the adult life of the Thomaner choir singers. The observations were not compared to other biological parameters. Walker et al. (1993) found that testosterone increased in pubertal stage III and voice decreased in stage IV in boys. They showed that a critical vocal cord length and testosterone value was required to initiate voice breaking. Testicular volume was a poor predictor of voice brake and saliva testosterone concentrations.

### **1.2.2. Video Stroboscopy / Electroglottography**

Phonetography in conjunction with stroboscopy are by J.Wendler suggested as basis investigations for voice disorders in the International Federation for Ear-Nose-Throat Societies. Stroboscopy has not been applied to quantitative evaluation of the voice but to differentiations between normal and pathological vocal folds. Videostroboscopy is an excellent means of visualizing the movements of the vocal folds and of presenting the many questions on the vocal folds (Wendler et al. 1989).

Pedersen et al. (1988) have prepared a video film with the stroboscopic equipment from Timcke at the phoniatics department of the medical university in Hannover. The film on Danish choir boys has, among others, been presented at the Voice Symposium in New York, Manhattan School of Music 1988. It was

difficult to visualize the quick register shifts of movements of the vocal folds in puberty seen with one cycle change on electroglottography.

The combination of stroboscopy and electroglottography seemed relevant at the time, when the discussion of the interpretation of the electroglottography curve again was blooming at the international conference of logopedics and phoniatrics in Interlaken in 1974. Schönhärl had performed a systematic study of stroboscopies in patients with voice disorders, but a statistical quantitative analysis of the treatment results was not possible (Schönhärl 1960, Pedersen, 1974, Pedersen et al. 1980).

Among others, Frokjaer-Jensen and Thorvaldsen (1968), based on the results by Svend Smith (1954) and Fabre (1957), sent a high frequency current through the throat at the level of the vocal folds and found the impedance variation representing the real time changes in the movements of the vocal folds in the electroglottograph. This research area culminated in, for instance, the research by Lecluse (1977) and Smith (1981). It has always been a good idea to combine several methods when one of them has an uncertain interpretation, which was the case till now with the amplitude and to a certain extent with the single parts of the electroglottographical curve. Anastopolo and Karnell (1988) and Karnell (1989) have made a video stroboscopy equipment combined with electroglottography. Now it is of course possible to combine several pictures of the high speed film screen by freezing some of them or comparing them with average pictures, as a basis for still more precise quantitative measures (Colton et al. 1989, 1995, Hirose et al. 1988). The equipment is clinically usable. The method seems optimal for illustrating the mucosal movements, as first described by Svend Smith in 1954.

#### **1.2.3.1. Fundamental frequency (F0)**

The electroglottographical signal was found suitable for giving information on the single movements of the vocal folds as well as for precisely registering contours of the fundamental frequency in running speech (Loebell 1968).

The firm FJ Electronics 1968, developed an electroglottograph. Based on this, Kitzing (1979) in his thesis analyzed fundamental frequencies. Guidet and Chevre-Muller (1979) have used an electroglottograph for fundamental frequency analyses in neurological patients as well as voice registers (Roubeau et al. 1987). The different configurations of the electroglottograms in singers compared to non-singers were discussed by Pedersen (1978). Also, the variation in fundamental frequency by measuring a histogram configuration has been carried out by constructors, particularly Fourcin and Abberton (1971) and discussed by Kitzing (1990).

Askenfelt et al. (1980) compared vocal fundamental frequencies measured with a contact microphone and electroglottography. But the historically interesting studies of fundamental frequency measurements in youngsters up until the last 15 years have been carried out primarily with pointer instruments and often with readings from of oscillograms (Baken 1987). Baken presents a survey of measurements of fundamental frequency studies as do Schulz-Coulon and Klingholz (1988). The newer algorithms need discussion, since they most often are related to technical not biological understanding.

The measurement using neural networks for pattern recognition could very well be developed for clinical use analyzing patterns of fundamental frequency (e.g. Elman & Zipser 1988, Rihkanen et al. 1994), but it will take time.

#### **1.2.3.2. Fundamental frequency in puberty**

A survey of measurements of fundamental frequency in children was given by Baken (1987) and also by Schulz-Coulon and Klingholz (1988), Hollien and Malcik (1967), Michel et al. (1966), McGlone and McGlone (1972), Hollien and Shipp (1972), Hollien et al. (1994).

Fairbanks et al. (1949) and Fitch and Holbrook (1970) have made basic studies on the development of fundamental frequency in children, but regrettably without pediatric evaluation. Vuorenkoski et al. (1978) have measured the pubertal mean fundamental frequency in endocrinological patients compared with pubertal stages. Heineman (1976) gave an overview of hormonal voice disorders, listening evaluation, stroboscopies, sonograms and semitone ranges of the voices of patients with gonad diseases. He describes the vocal cords in precocious puberty as thickened with reduced marginal movements at stroboscopy, a bass voice and a semitone range of 1 octave. Bastian and Unger (1980) have compared the fundamental frequencies with pubertal stages.

Unfortunately, the literature up till now does not contain many studies where sexual maturation measured by hormones is shown to be related to the voice. Considering the voice as an interesting biological parameter is, of course, not limited to puberty, but also voice in menopause as compared to puberty in girls has had interest (Truuverk & Pedersen 1992).

Calculation with biologically adapted algorithms gives new perspectives for clinical use. (Bühning & Pedersen 1992, Krusnevskaia & Pedersen 1992). The biological effect of testosterone treatment in the senescent was discussed by Behre and Nieschlag (1995). It is continually necessary for the biological voice research to renew itself in connection with the best research in other fields (e.g. in acoustical science in

music (Siegel 1994) as well as neuroendocrinology of estrogens in puberty (Rodrigue-Sierra 1986, Blaustein 1986).

#### **1.2.4. Pubertal development**

Puberty is defined as the achievement of reproductive function, clinically reflected in obtaining secondary sex characteristics. Normal pubertal development is complicated. Brook (ed.) provides a survey (1995), based in part on Tanner and Whitehouse (1976).

In Western European males a peak height velocity is seen from the age of 12-16 years. The pubic hair stage II ranges from 9.5-14 years and pubic hair stage III from 11.5-16 years. Stage IV ranges from 12-16.5 years and pubic hair stage V from 13-17.5 years of age measuring the growth of the hair area in the pubic region. The genital stages related to a testicular enlargement measured with an orchidometer comparing the testis to a standard, changes from genital stage II at 10-14 years and genital stage V from 13-17 years of age (Brook 1995).

In Western European females the time of menarche is at 11-15.5 years, the peak height velocity at 10.5-14 years. The pubic hair stage II ranges from 9-14 years, pubic hair stage III from 10-14.5 years and pubic hair stage IV from 10.5-15 years. Pubic hair stage V (young adults) ranges from 11.5-19 years. Breast stage II ranges from 9-13.5 years, stage III from 10-15 years, breast stage IV from 10.5-15.5 years and breast stage V from 12-19 years of age (Brook 1995).

Mean plasma testosterone in normal boys by the stage of maturation gradually changes from stages I to V, and the same is the case for estrogens in adolescent females (Brook 1995).

Brook suggests that voice development only begins with a voice change beginning at 13 years of age, and the adult voice is reached by 15 years of age. A reference is given to Karlberg and Taranger (1976).

Calcium metabolism is more related to sexual hormones than to age. This situation could be the same for the voice (Krabbe 1989). The heights of Danish children were examined by Andersen (1968), later by Roed et al. (1989) and Hertel et al. (1995), they correlate well to our studies.

Brook mentions that knowledge on the heart and respiratory organs in puberty is limited, and that these parameters till now have been related to height and development of secondary sex characteristics (1995). This seemed to have been the case for voice phenomena in the paediatric literature as well. Hagg and Taranger (1982) describe the voice as childish, pubertal or adult. Walker et al. (1993) found the significant

increase of testosterone in pubertal stage III and vocal cord length inversely related to vocal frequency decrease in pubertal stage IV.

Kahane (1982) analysed the development of the thyroid cartilage in puberty in relation to height. Kurita et al. (1980) have measured the enlargement of the vocal folds in puberty. The entire length of the vocal folds gradually develops until the age of 20 years in both sexes, and in adults the vocal length in males is 17-21 mm, and in females 11-15 mm. The length did not differ between the sexes under the age of ten, above the age of 15 the vocal fold is longer in males than in females. In the vocal folds of 12-year-olds there is a slight differentiation of the layer of elastic fibres from that of collagen fibres. In the 16-year-olds there is a layer structure as observed in adults (Hirano et al. 1983). Hirano et al. (1988) found a greater tension effect of the cricothyroid muscle in females than in males, which together with a greater dorsal component in the abduction of the tip of the vocal process of the arytenoid cartilage in females might have important physiological and clinical implications. Kersing (1983) found no evidence that the vocal musculature differs in any important respect from other skeletal muscles. His findings tend to support the hypothesis that the primary function of the vocal cords is as that of a sphincter and that sound production is a secondary functional development due in part to the development of type I muscle fibres. This corresponds to Sato and Hirano (1995) who studied the development of maculae flavae at the ends of the vocal ligaments which are immature at birth. It is suggested that the tension during phonation (vocal fold vibration) causes the fibroblasts to be in an active phase and to synthesize fibres. Hollien (1983) comments that the control of vocal frequency appears to be mediated by variation in vocal fold mass and stiffness plus changes in the subglottal air pressure.

Many studies have been carried out on rats and dogs etc., however, singing canaries may be of greater interest, as androgen induced behavioural effects on singing were found as a probable secondary or independent result of androgens' primary and immediate action on target gene transcription (Nastiuk & Clayton 1995). Frogs have also been studied, and it has been suggested that estradiol may increase transmitter release at laryngeal synapses during juvenile development (Tobias & Kelley 1995).

In male frogs a rapid fibres addition was seen in the male laryngeal muscles at time of sexual differentiation (Marin et al. 1990, Tobias et al. 1991).

Normal sexual endocrinological development is regulated by gonadotropin releasing hormone from the hypophysis, a decapeptide (Brook 1995). Thereafter, the pulsating secretion of luteinizing and follicle

stimulating hormones from the hypophysis commences, which regulates the growth of the testes and the ovaries, where the sexual hormones are produced. Our measuring methods are described by Lykkesfelt and co-workers (1985). The measurements were comparable to others (Tanner & Whitehouse 1976, Apter & Vihko 1985).

Strel'Chyonok and Vihko (1985) give a survey of the function of the sex hormone binding globulin (SHBG). With the measurements of steroids in saliva new possibilities open up in pathology for voice analysis, comparing voice and hormonal pathologic development in boys as well as girls (Young et al. 1988).

In humans most pubertal pathological histories are case stories of relations between testosterone and the lowering of the voice (e.g. Yukizane et al. 1994), as well as a longitudinal study of treatment of girls with Turner's syndrome, with growth hormone, oxandrolone and ethinyl estradiol showing a distinct decline in speaking fundamental frequency during the first year (Andersson-Wallgren & Albertsson-Wikland 1994).

With the new understanding of brain regulation of sex hormone binding globulin (SHBG), a possibility for bringing pubertal voice studies into brain research has opened up, e.g. Blaustein (1986) and Miranda et al. (1996), who measured steroid receptors and hormone action in the brain.

### 1.3. Methods

Apparature	Original paper				
	I	II	III	IV	V
Electroglottograph FJ electronics 830	+	+	+	+	
Storage oscilloscope Tectronix 510	+	+	+	+	
Taperecorder Tandberg two tracks	+	+	+	+	
Sound level meter B and K 2205, B and K 2236	+	+	+	+	+
Computer Portable		+	+	+	
Phonetograph 8301		+	+	+	
Stroboscope Timcke KS 3 B and K 5066	+	+	+	+	+
Spectral analyzer Nicolet 440 Key elemetrics 4300B		+	+	+	
<b>Hormones</b>					
Androgens		+	+	+	+
Estrogens		+			
<b>Pubertal pediatric analysis</b>					
Height, weight, pubic hair stage		+	+	+	+
Testicular volume stage breast stage and menarche		+			

Table 1 - Overview of the instruments and parameters used in the present study based on thesis 1997 Oulu

#### 1.3.1. Voice range profiles / phonetography

The pitch and loudness ranges of the adolescent singers were measured according to the standard proposed by the Union of European Phoniaticians (1981) and stored in our phonetograp. In phonetography, the highest and the lowest sound level the subject is able to produce at a given fundamental frequency (F0) is recorded. Repeating this measurement over the total F0 range of the subject provides a documentation of the total biological capability of a given person. Standard semitones are chosen. The equipment, developed by H. Lindskov Hansen, stores the measurements, which are then at one's disposal for statistical calculations.

Computed area measurements of the total distance between the curves of soft and loud selected semitones for the total frequency range were made with interpolation of the, for practical reasons, omitted semitones.

In the audiogram, only the softest loudness measurement is used. In the phonetogram, the lowest sound pressure level which the singer/speaker is capable of producing is of interest, but also the highest SPL. If the

person has the capability to change the SPL from very weak to very loud in a large frequency area, then the voice has a capacity for a higher degree of EXPRESSION.

The measurement method shows the total biological capability range of a voice. Other examination principles should be related to this measurement. For example will a stable examination showing high musical qualification in a large frequency and SPL range serve as a documentation of better singing quality than in a small SPL and frequency range. The measurement of phonetogram areas is made in Hz x dB(A). As in traditional audiometry certain frequencies were selected: the frequencies of a piano - the semitones. Hence the phonetographic area measurement was modified to: semitones x dB(A), independent of the scales on the graph.

At the onset of our studies planimetric calculation was used, which is why cm<sup>2</sup> for the phonetogram area is used in our material. Still a conversion factor of 1 cm<sup>2</sup> being 32 dB(A) x semitones seemed relevant to use, taking the standard paper of the UEP standard measurement proposal into account. After we had developed computerized equipment, including software for phonetography calculations this was no longer necessary (Pedersen et al. 1995).

#### **1.3.1.1. Instrumentation**

The phonetograph was developed with possible consecutive RMS measurements of 1/2 seconds or 1, 2, 3, 4 or 5 seconds by minimal or maximal intensity. Each desired semitone was measured with root-mean-squares (RMS) and stored. 1/2 second was used. The measurement method was compared with the manual method and an agreement of 96% was found (Sturtzebecker et al. 1982, Pedersen et al. 1984 and Pedersen et al. 1988).

As the phonetograms were in any event stored, it seemed relevant to develop software for statistical treatment wherein not only averages of phonetograms in semitones x dB(A), but also 95% intervals could be calculated. The number of averagings is only limited by computer capacity (Pedersen and Lindskov Hansen 1986).

#### **1.3.1.2. Analysis**

The total semitone range, the lowest semitone, the middle semitone and the area in semitones x dB(A) were the preferred statistical calculations to be used in the phonetograms. The highest semitone is variable, and depends on training more than biology. In the beginning, before the averaging program was made the areas were calculated through planimetric measurement with a conversion factor of 1 cm<sup>2</sup> = 32 semitones x dB(A).

The total semitone ranges were given in semitones, not in hertz, in this way the statistical possibility for errors is taken into account that ranges of semitones are logarithms and hertz are linear calculations for the frequencies (geometric means used). DBs are logarithms. The measurements were carried out in the singing school and in the ENT clinic. The phonetograph stored the data connected via a portable IBM computer.

### 1.3.2. Fundamental frequency (F0) in running speech

The fundamental frequency was registered electroglottographically, measuring the cycles: the curve from zero to zero in the electroglottogram. Mean values (after calculation in the software program for 2000 cycles) were expressed in hertz, 95% intervals of the fundamental frequency were expressed in semitones: the tone range in continuous speech. A portable computer, an electroglottograph from FJ electronics, type 830, a sound pressure level meter type 2208 and a stroboscope type 5066 from Bruel and Kjaer, and Timcke, KS 3 were used, a Tectronix oscilloscope controlled the curve position.

The text read was from a book edited by the International Phonetic Society (1964) and precisely translated into Danish by a phonetician ("The North wind and the Sun" translated by Copenhagen University, Phonetic Dept.).

#### 1.3.2.1. Stroboscopy with synchronous electroglottography

We have conducted a synchronized examination of stroboscopy and electroglottography on untrained hospital employees for analysis of the single curves in the electroglottogram with the Danish electroglottograph (FJ Electronics).

#### 1.3.2.2. Electroglottographic measurement in a reading situation

The software based on 2000 duty cycles was used during the reading of the standard text with the mean fundamental frequency in Hz and the 95% intervals in semitones, the signals being grouped in semitones from 60-684 Hz.

#### 1.3.2.3. Subjects

Study subjects	Original paper				
	I	II	III	IV	V
48 boys			+	+	
47 girls		+			
3 boys					+
20 adults (14 females and 6 males)	+				

Table 2 - Overview of the single studies

In 20 hospital employees were earlier used. 48 boys were examined, and 47 girls were tested for voice parameters, the success rate for blood tests being 41 girls. Three boys were examined six times, beginning at the end of the 7th grade.

The 48 boys and 47 girls were part of the voice study which was cross sectional with 4-5 pupils in each school class, all being between 8 to 19 years of age. All were musically gifted judged by professional evaluation (Seashore 1938, Pedersen 1992, Dejonckere et al. 1995) with evaluation of vibrato, test for rhythm and tone jumps (ref. by Pedersen 1991 b ) and presentation of a standard song including high notes: "I Østen stiger solen op", by the composer Carl Nielsen. Stroboscopically nothing abnormal was found, the pubertal development was evaluated as normal by the paediatrician in our team, based on the standards referred by Brook (1995).

All were placed in traditional voice categories by singing teachers who knew the pupils well (1 and 2 sopranos, altos, tenors and bassos).

## **1.4. Results**

### **1.4.1. Voice range profile measurements**

On the abscissa of the voice range profile piano semitones are selected, and the corresponding loudness intervals of a voice are measured. The resulting figure, calculated as the phonetographic area shows the vocal capacity of a voice, including register shifts and possible unstable parts of loudness regulation. During the past decades the method has proved its value in evaluating voices.

One of the problems with the method has been connected with the frequency weighting of the phonetograph 8301. Some researchers use a linear frequency response or a C-weighting, as they claim it is only possible to accurately register the lowest tones by this. Others prefer an A-weighted frequency response. The reason for this is that it makes it much easier to get a relevant signal-to-noise ratio in noisy surroundings, for the A-curve cuts away most low frequency disturbances. The A-curve also results in voice range profiles which correspond to the audible sound impression of the ear due to the reduced low-frequency sensitivity of the ear.

The spectral composition influencing the contour of the voice range profile was analyzed in the instrumental set-up of an A-curve and a C-curve. The tone generator in the phonetograph 8301 was constructed with

tones having a high harmonic content. A series of tones from 58-1865 Hz with a spectrum which resembles a soft voice quality, were supplied to a loudspeaker. The sound pressure level at the microphone location was kept constant at two levels: 100 dB and 60 dB respectively, by means of a simultaneous SPL monitoring with a calibrated Bruel and Kjaer sound pressure level meter type 2236, which has built-in frequency weightings according to curve A and C frequency response. The frequency weighting of curve A and the output from phonetograph 8301 with the above mentioned input signal was not dampened by 30 dB at 50 Hz relative to 1000 Hz, but only by 10 dB.

The reason is that it is not the level of the fundamental frequency alone which determines the output level, but the sum of all the harmonics (which are not so strongly dampened as the fundamental frequency).

The influence on a phonetogram of a type A-weighting relative to a type C-weighting was analyzed. However, as the strongest energy at low frequencies is placed in the first formant, the discrepancy is less pronounced in real speech and singing especially if the test tone used for phonetograph 8301 is an "ah".

The results indicate that it is preferable to use the A-weighting for recording voice range profiles, partly because the error made is not serious, and partly because of the great advantage that it is possible to make the recordings in noisy surroundings (up to 30-35 dB SPL (A) noise).

#### **1.4.2. Measurement of vocal fold movements**

In the study the electroglottographic curve was used to register the stroboscopic picture. The phases were marked with a photocell attached to a larynx mirror and connected to an oscilloscope and a tape recorder in 20 normal non-singers. This makes it possible to plot the variations in the curves. Measurement of coefficients for opening and closing phases was carried out, also in those cases where the electroglottographic curve alone could not be used to define these coefficients. The variations were seen in the form of the electroglottographic cycle. The cycles were dependent on frequency variations alone.

On the basis of this experience, a computer program was developed for F0 measuring 2000 consecutive electroglottographic cycles during reading of a standard text.

The average values of signals were given in Hz and the standard deviations in semitones. A range from 60-784 Hz was analyzed. The analysis was made with the electroglottograph attached to an oscilloscope connected to a computer calculating the signals.

In comparing the signals with the stroboscopic inspection the earlier discussion of the accuracy of the electroglottographical signal for measurement of fundamental frequency was brought to an end.

### **1.4.3. F0 in running speech in a reading situation in boys in puberty**

The variation of fundamental voice frequency measured by the average of 2000 consecutive electroglottographic cycles in a reading situation was examined in relation to pubertal development and androgens. Fundamental voice frequency, among other parameters, was related to height ( $r = -0.82$ ), pubic hair stage ( $r = -0.87$ ), testis volume ( $r = -0.78$ ) total testosterone ( $r = -0.73$ ) and serum hormone binding globulin ( $r = 0.75$ ).

Single observations of fundamental frequency showed a clear grouping of results. Serum testosterone of more than 10 nmol/l serum probably represents values for a boy in puberty. There seem to be comparable relations with other androgens.

The voice parameters in 48 boys, aged 8-19 years include F0, the lowest biological semitone, the middle biological semitone in the voice range profile, the F0 range in running speech in a reading situation and the voice range profile area (phonetogram area).

The connection between F0 in running speech (abscissa) and SHBG, serum testosterone, testis volume and pubic hair stage has been documented.

The measurements were divided according to the pediatric tradition for pubertal measurements: three age groups - the first considered pre-pubertal, the second pubertal and the third post-pubertal. The voice analyses were compared with the pubertal stages and the androgens, and a correlation to F0 was calculated with the BMDP statistical program. The serum testosterone, testis volume and pubic hair stages are closely connected to SHBG and significantly related to the F0 in running speech in a reading situation.

### **1.4.4. F0 in running speech in a reading situation in girls in puberty**

As with the boys, the change in fundamental voice frequency in running speech in a reading situation in female puberty was analyzed in 47 voice-trained girls, through a comparison of 2000 consecutive electroglottographic cycles. The results were compared with serum concentrations of androgens and estrogens (estradiol, estrone and estronesulphate) and somatic puberty (weight, height, breast stages and pubic hair stages). Fundamental frequency (F0) was related only to estrone  $r = -0.34$  ( $p < 0.05$ ). However, the tone range in running speech in a reading situation and the lowest biological semitone in the voice range profiles were found to be significantly correlated with several of the puberty and hormone parameters.

A traditional division into a pre-pubertal, pubertal and post-pubertal group was made for voice parameters, pubertal stages and hormones. A significant change was seen for estrone, estrone sulphate, DHEAS and

androstendione between the 3 groups. This was also the case for the voice parameters F0 range, the voice range profile area (phonetographic area) and the lowest semitone.

#### **1.4.5. Specific results**

The observations were transformed logarithmically in order to obtain normal distribution. The differences between age groups were analyzed through one-way analysis of variance (ANOVA), and correlation coefficients were calculated for all pairs of variables to illustrate the connection between them. The influence of a common age-dependency was studied by means of partial correlation coefficients. A multidimensional linear regression analysis was carried out with F0 in running speech in a reading situation as the dependent variable and puberty stage and hormone levels (in all 12 variables) as describing factors. BMDP programme (9R) with Mallow's CP as a test criterion was used. This test was carried out for 48 boys and 41 girls and for the two subgroups of 41 girls, pre- and post menarche.

For the 48 boys a significant relation was found between 11 boys in the pubertal stages II-IV, age 13.5, F0 219 Hz and SHBG, indicating an age independent relation connected to falling F0. For the 41 girls, where hormonal analysis and voice analysis were available the best set of describing variables were F0 range and estrone sulphate. Before menarche, height and estronesulphate had a p value of  $p < 0.001$ , pubic hair stage  $p < 0.05$ . After menarche F0 range had a value of  $p < 0.001$  and time after menarche  $p < 0.01$ . Age showed a relation to F0 of  $p < 0.05$ .

**Voice range profiles** of an untrained small boy had a small semitone and loudness range especially for soft notes. For the trained singer the highest notes, in particular, changed from a2 to g3. The loudness was better for soft as well as loud SPL. Two register shifts were seen in the middle at different places for loud and soft intonation. The typical pubertal register shift can be defined, and a lowering of the lowest semitone and a high loudness range for the lowest register shows up after puberty. The upper register is of course less defined. For a post pubertal young man, the lowest semitone and loudness range is preserved and new stable semitones are built in a higher register.

Voice categories in trained choir girls show greater loudness range in the upper part for sopranos and in the lower part for altos. On the abscissa the semitone ranges which were usable in a choir situation of phonetograms can be marked. (1st soprano, 2nd soprano, child alto, post-pubertal 1st soprano, 2nd soprano and alto). It is noted that the difference between the pre- and post-pubertal first sopranos and altos for the lowest semitone is f->e and d->c respectively. The register shift is stable for the highest loudness in the post

pubertal girls (= or > 90 dB(A)). Compared with boys the reduction of loudness at the register shift and in the upper register gives an impression of a pubertal change that, in principle, is of the same kind as in boys.

Computed averages of the yearly differences in the voice profiles of 48 boys and 47 girls can be made.

The abscissa marks the given semitones and also the frequencies of the octave shifts. The ordinates present dB(A). The statistical 95% deviations were reduced with age as given for the measured loudness. For the lowest semitones the child measurements have small deviations. From 12-17 years, the variation in pubertal lowering of the lowest semitone corresponds to the statistical results showing that the lowering was related to the increase in testosterone values more than to age. The main result is that the lowest tone only drops by 2 semitones. The areas in semitones x dB(A) in 8-10 year old girls, especially the highest loudness is smaller than in boys. But in the post-pubertal young women, the size of the semitones x dB(A) is equal to the size in young men, with a higher location in relation to octaves.

Clarifications of the phonetograms in the 48 boys and 47 girls in voice categories are defined by the singing teachers. There is a need for voice category analysis also in untrained singers also, when phonetograms are used for advice. It can be seen that especially for the post pubertal young men the maximal loudness range gradually lowers toward the second basses, meaning that not only the semitone ranges but also maximal loudness is decisive for the position in a choir. The same tendency is seen for post pubertal young women. The elite phenomenon of singing is illustrated for 1. sopranos. Deviations are high at c3 (1047 Hz). (Pedersen et al. 1982, 1983, 1986, 1990, 1991.a, Behrendt & Pedersen 1989).

An exact measurement of the fundamental, the lowest partial in the spectrogram is made by registering the continuous changes of the basic voice sound with all its nuances of frequency.

### **1.4.3. Hormone and pubertal stage analysis**

The hormonal analyses were based on our knowledge of probable changes in puberty (Brook 1995), and carried out in cooperation with the hormonal department, Statens Seruminstitut Copenhagen Denmark. The children were evaluated down to 8 years of age because the adrenarche (increased adrenal function of that age) could perhaps show relations that would aid in understanding of the puberty. The following values were analyzed: serum testosterone (free and total, which are closely related), dihydroepiandrosterone sulphate (DHEAS), delta 4 androstendione and the transport globulin for testosterone: sex hormone binding globulin (SHBG). For the girls the analysis also included: estradiol (E2), estrone (E1) and estrone sulphate (E1 SO<sub>4</sub>).

The relations and formation and time of function for androgens and estrogens are of course complicated, all

the androgens and not only the gonadal hormones were measured. The results of analyses, including the tables and figures, give more details on the relationship between sexual hormones, growth regulation of the body and the specific voice-related changes, providing a better understanding of their possible interaction with growth hormones. Height, weight, testis volume measured with an orchidometer, pubic hair stage and breast development were evaluated in stages of puberty, as suggested by Krabbe, the paediatrician on our team. Puberty was defined as achievement of reproductive function, in practice, defined as obtaining secondary sex characteristics, pubic hair stage V-IV (Brook 1995).

#### **1.4.4. Specific statistical calculations**

The logarithmic criteria used here are based on geometric means and as such substantially stronger than linear ones. A one-way multivariate analysis was carried out, classified by fundamental frequency (F0) in running speech in a reading situation, in order to find predictions for the decline of puberty. Correlation coefficients have been calculated for all variables, in order to find connections between them, to calculate age dependency and to show age independent parameters, all with the assistance of partial correlation coefficients (BMDP).

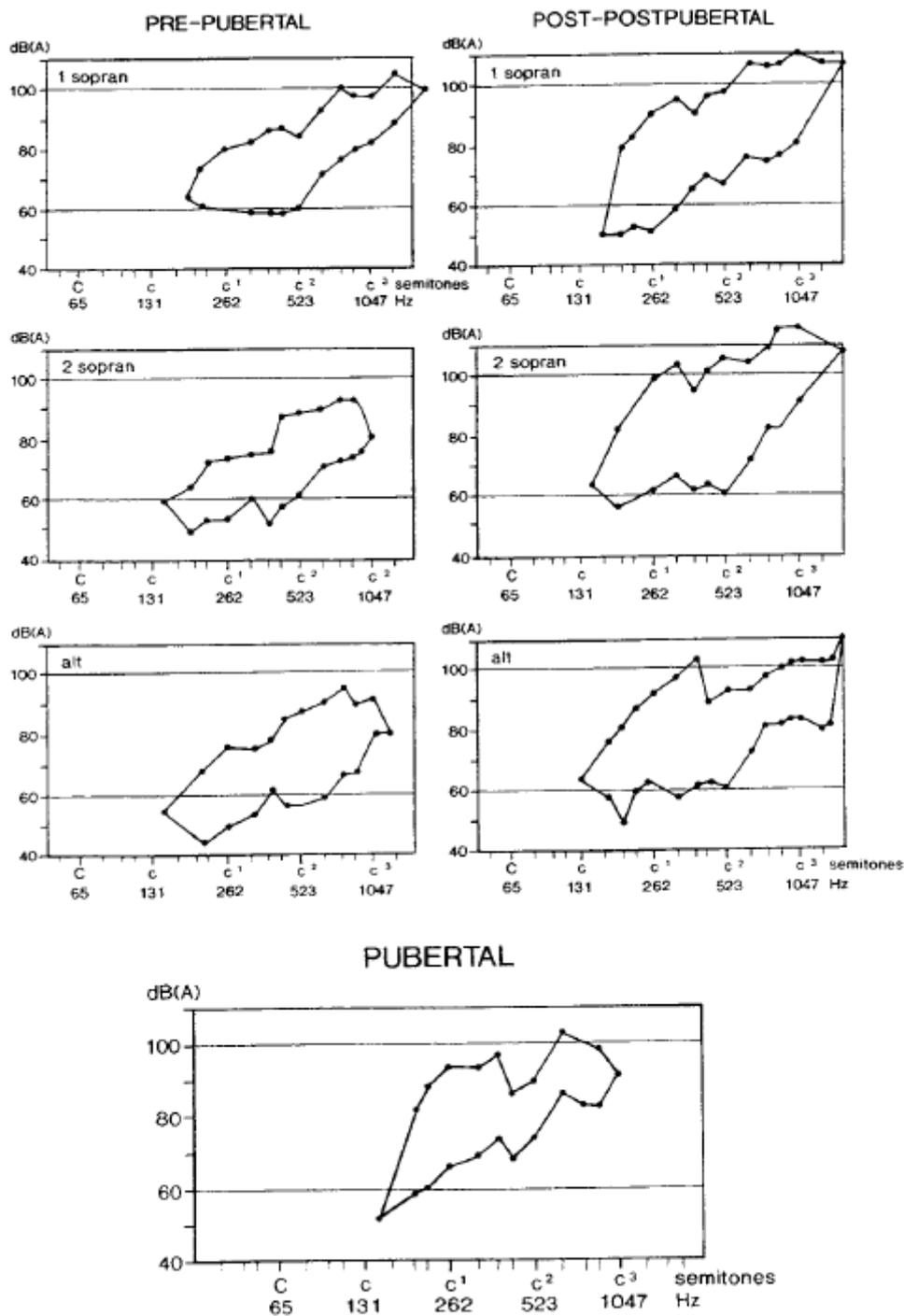


Figure 1 - Examples of voice categories in girls. Greater loudness variation is seen in the upper part for sopranos and in the lower part for altos. (1. soprano, 2. soprano, child alto, post pubertal 1. soprano, 2. soprano and alto). Lowest a pubertal girl age 14.8 years is presented with lower loudness range in the upper register.

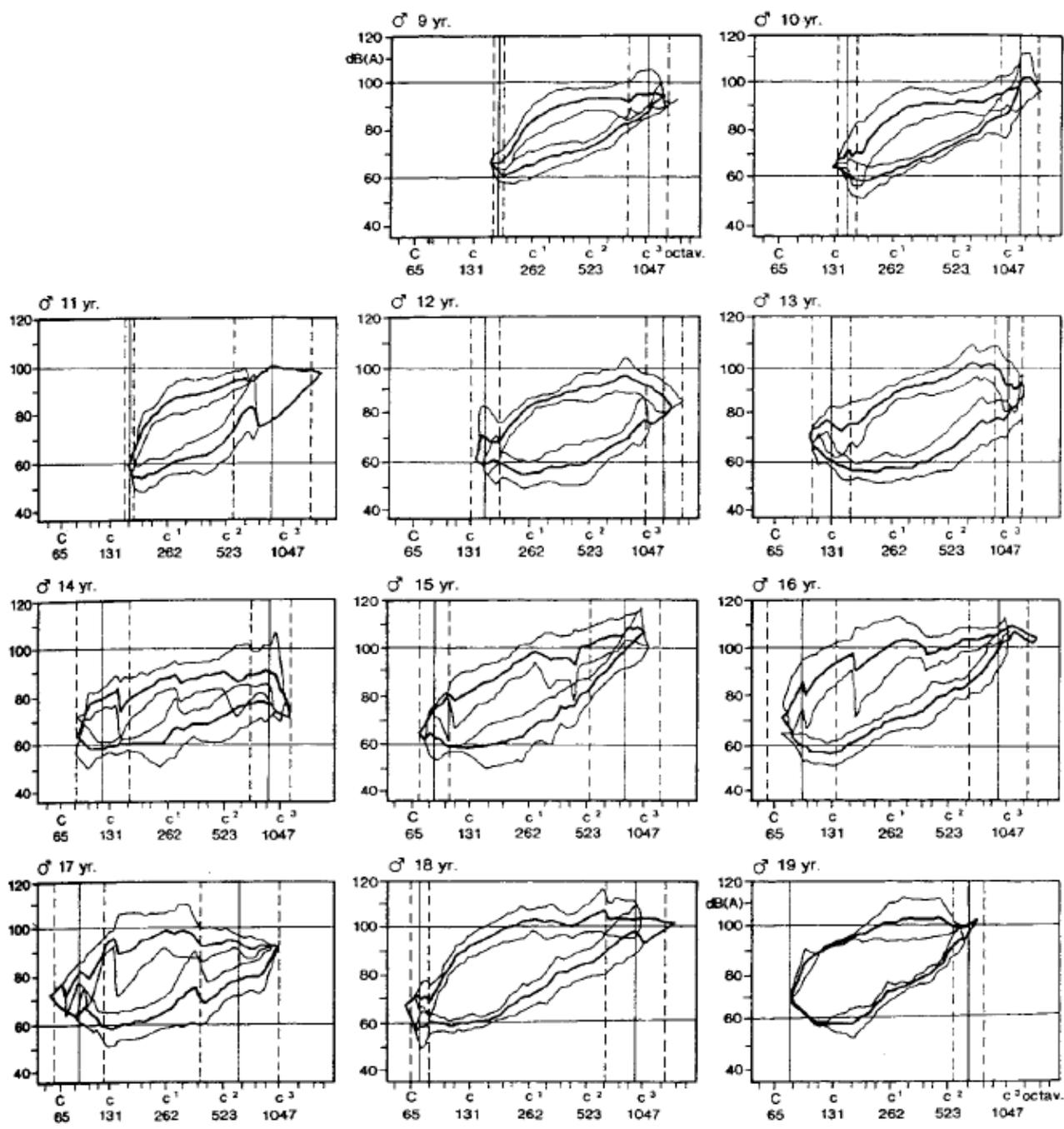


Figure 2 - Average age related development of voice with standard deviations of boys in an amateur choir. The abscissa marks the given semitones, and the frequencies at the octave shifts. The ordinates present dB(A).

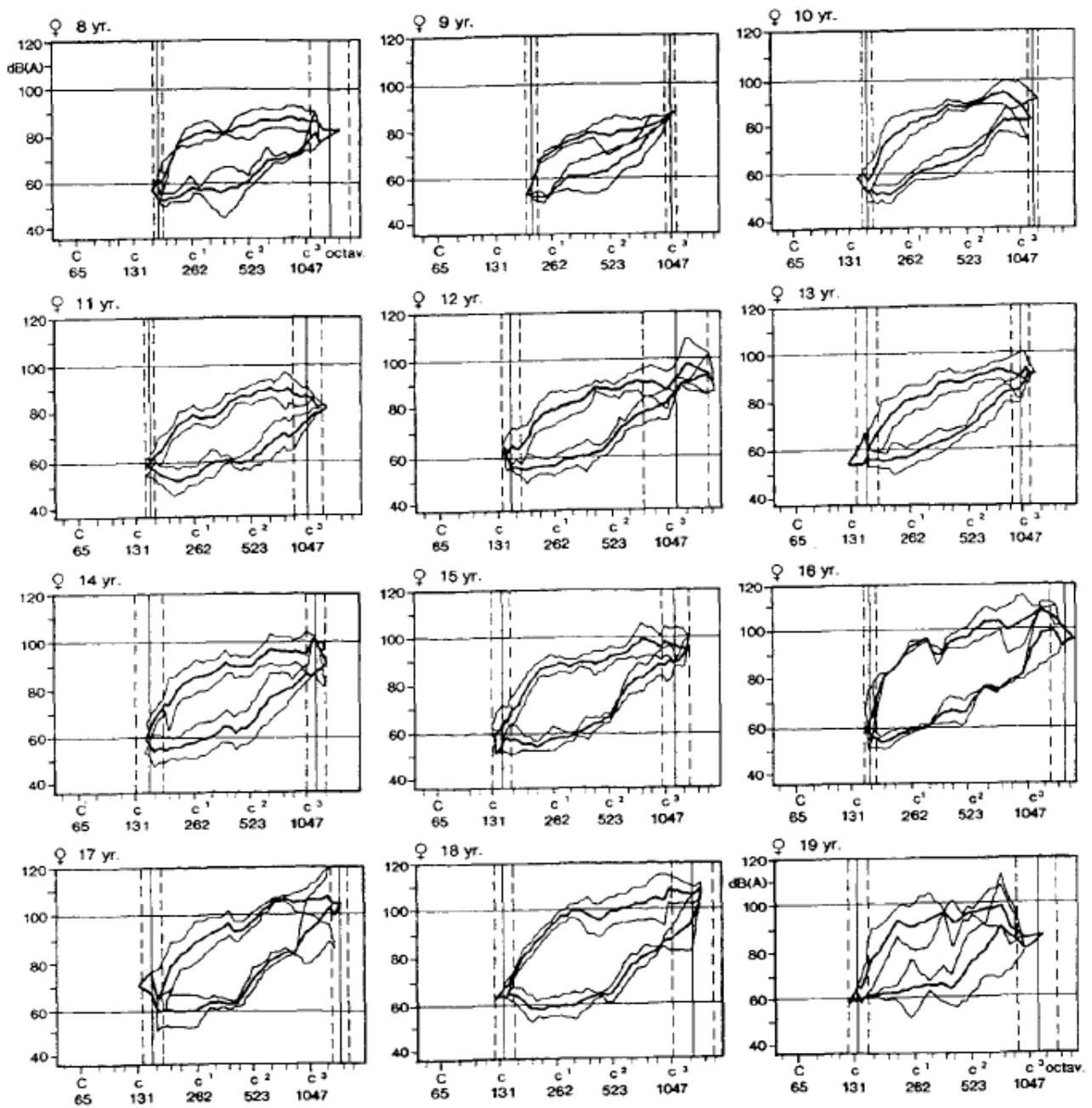


Figure 3 - The averaged yearly change of phonetograms with 95% deviations in puberty in girls. The abscissa marks the given semitones, and the frequencies at the octave shifts. The ordinates present dB(A).

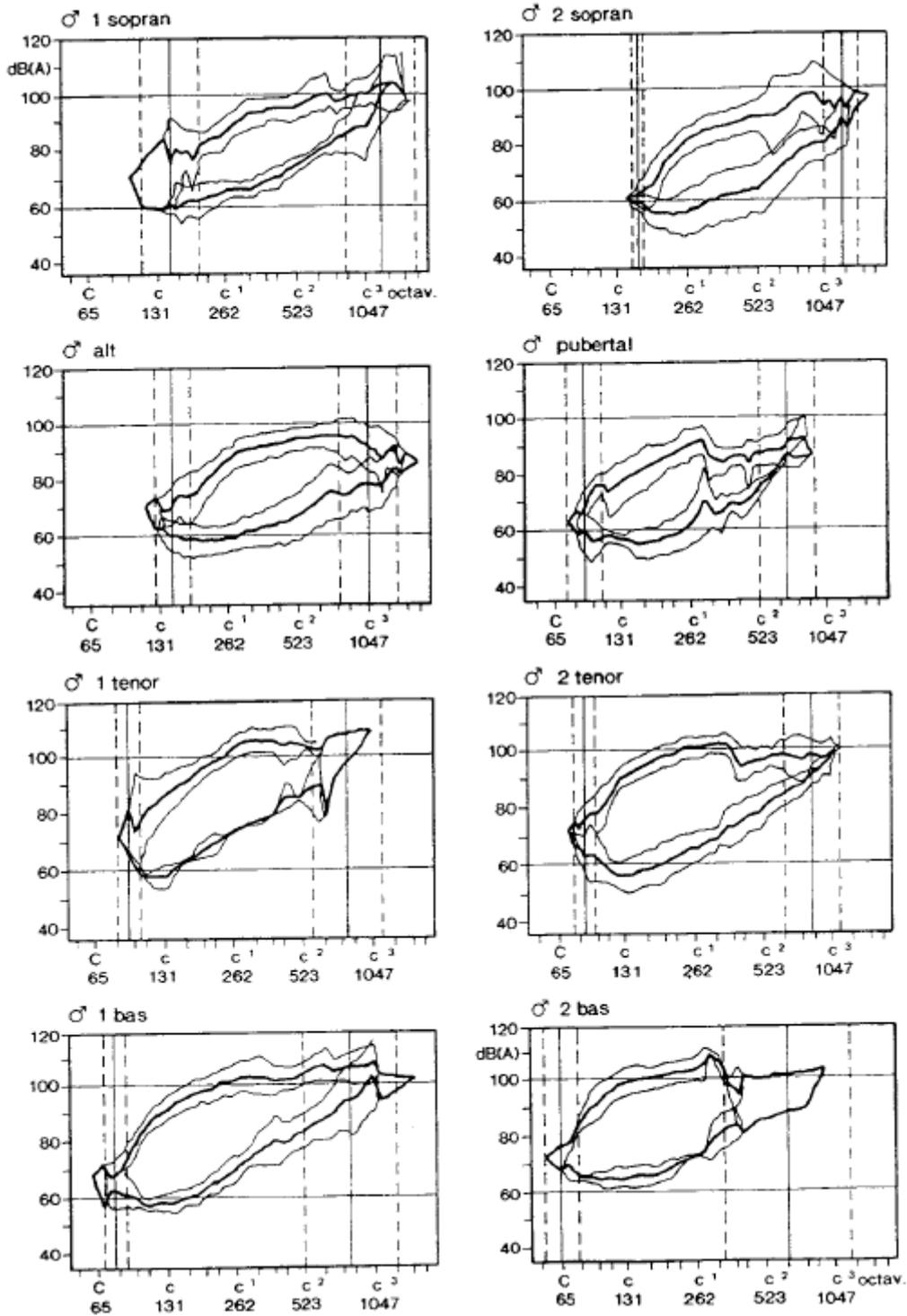


Figure 4 - The averaged phonetograms and 95% deviations of singing categories of boys in a boys and young men's' amateur choir defined by the singing teachers. A pubertal group is also given. The abscissa marks the given semitones, and at the octave shifts the f

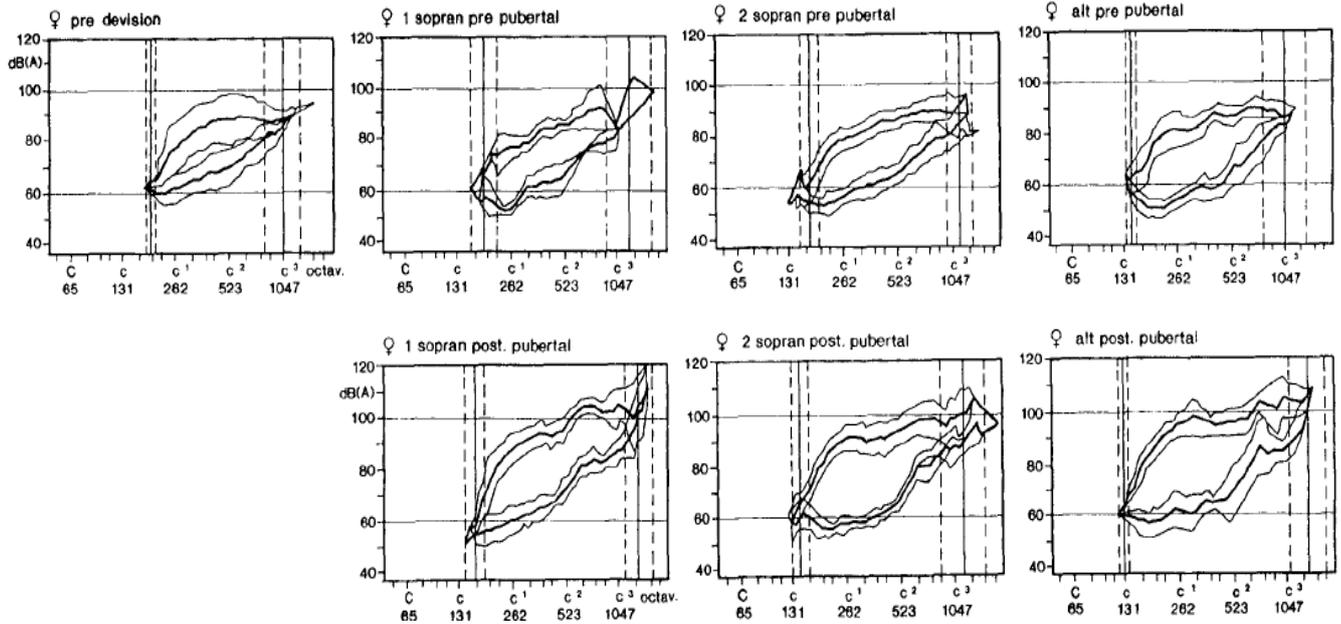


Figure 5 - The averaged phonetograms and 95% deviations of categories of girls and young women in a girl choir as defined by the singing teachers. A division between pre-pubertal and post-pubertal girls was made. The abscissa marks the given semitones, and at the octave shifts the frequencies are also given. The ordinates present dB(A). No pubertal group was found by the singing teachers.

The correlation coefficients ( $r$ ) between  $F_0$  and these variables are also given.

No.		19	15	14	
Age grouping (years)		8.7-12.9	13-15.9	16-19.5	$r$ to $F_0$
symbols referring to Figs. 1 and 2		●	○	△	
$F_0$ in continuous speech	Hz	273	184	123	
Voice range in continuous speech	Semi tones	3.7	4.8	5	-0.57
Total tone range	Semi tones	34.4	37.5	41.4	-0.46
Lowest biological tone	Hz	158	104	72	0.93
Middle biological tone	Hz	435	321	254	0.47
Phonetogram area	cm <sup>2</sup>	19	28	34	-0.50
Serum testosterone	nmol/l	0.54	10.5	18.9	-0.73
Dihydrotestosterone	"	0.18	1.21	1.57	-0.68
Free testosterone	"	0.007	0.14	0.33	-0.76
Sexual hormone binding globulin	"	134	66	45	0.75
Delta-4-androstendione	"	0.59	1.7	2.5	-0.65
Dihydro-epi-androsterone sulphate	"	1400	4100	5900	-0.71
Height	cm	143	157.1	180.6	-0.82
Testis volume	ml	2.3	13	20	-0.78
Pubic hair	Stage	1-3	1-5.5	5-6	-0.87

Figure 6 - Development of fundamental frequency during puberty in boys related to hormonal development

		<i>Age (years)</i>			<i>Signifi- cance</i>
		<i>8.6-12.9</i>	<i>13-15.9</i>	<i>16-19.8</i>	
Total number		18	12	11	
Oestrone (E1)	pmol	57	104	123	**
Oestradiol (E2)	pmol	73	135	108	
Total testosterone	nmol	0.5	0.76	0.94	
Free testosterone	nmol	0.006	0.037	0.009	
Oestrone sulphate (E1SO <sub>4</sub> )	pmol	732	1924	2342	**
DHEAS	nmol	3210	3700	7200	**
Androstendione	nmol	1.44	3.28	3.43	*
Sex hormone binding globulin (SHBG)	nmol	153	130	123	
Menarche		+4	+9	+11	
Pubic hair stage		1-4	2-5	4-6	
Mamma development stage		1-4	2-5	5	
Height		144.5	159.7	165.1	
Weight		37.8	53.0	64.4	
Fundamental frequency in continuous speech	Hz	256	248	241	
Tone range in continuous speech	+	3.7	4.2	5.2	**
Tone range in singing	+	23	30	38	
Phonotographic area	+ +	17.3	21.8	28.3	**
Phonotogram lowest tone	Hz	166	156	145	*
Phonotogram middle tone	Hz	429	409	413	
Phonotogram highest tone	Hz	1136	1105	1263	

+ , measured in semitones, + + , cm<sup>2</sup> conversion factor: 1 cm<sup>2</sup> = 32 semitones × dB(A).

Figure 7 - Development of fundamental frequency during puberty in girls related to hormonal development.

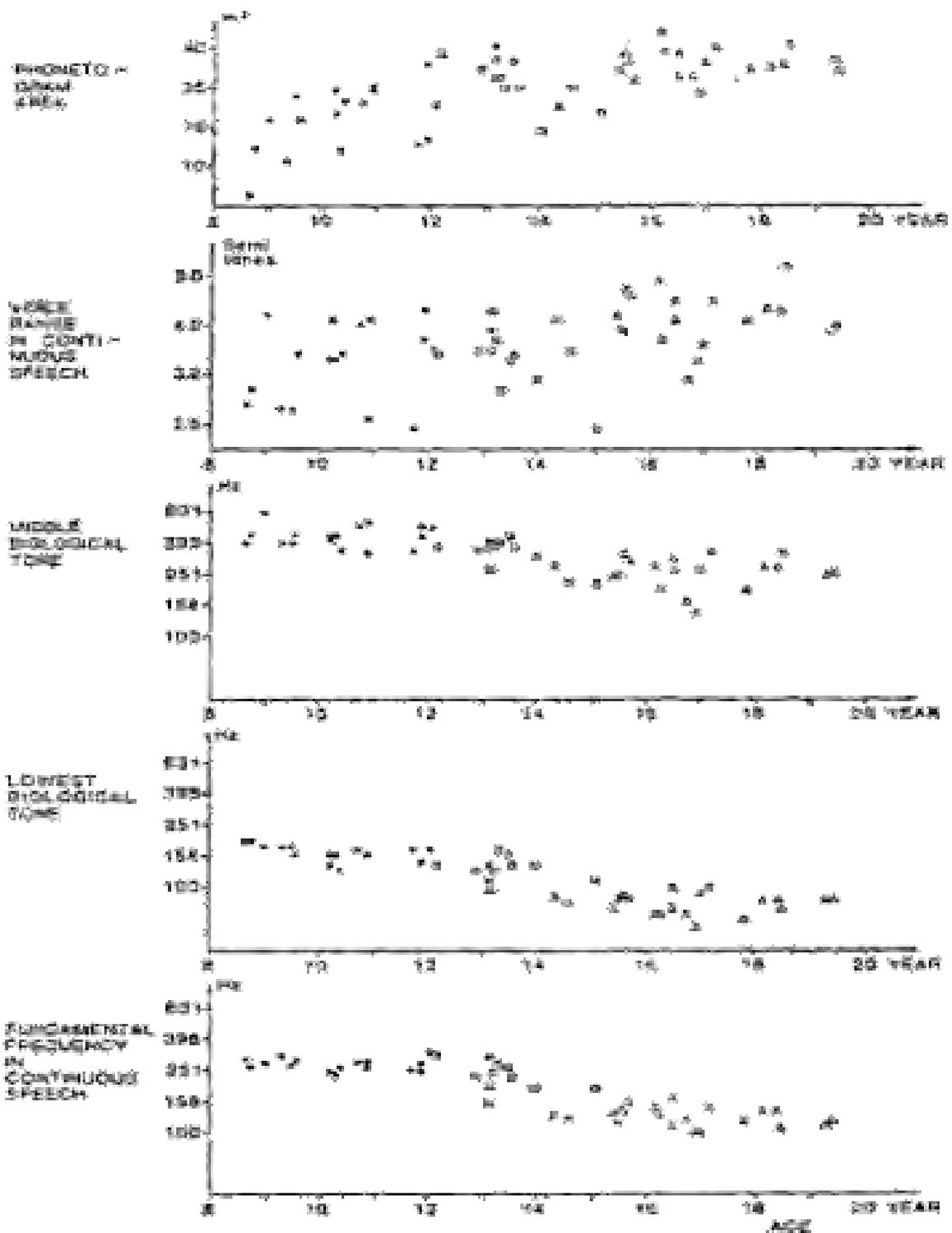


Figure 8 - The fundamental frequency in boys related other voice parameters

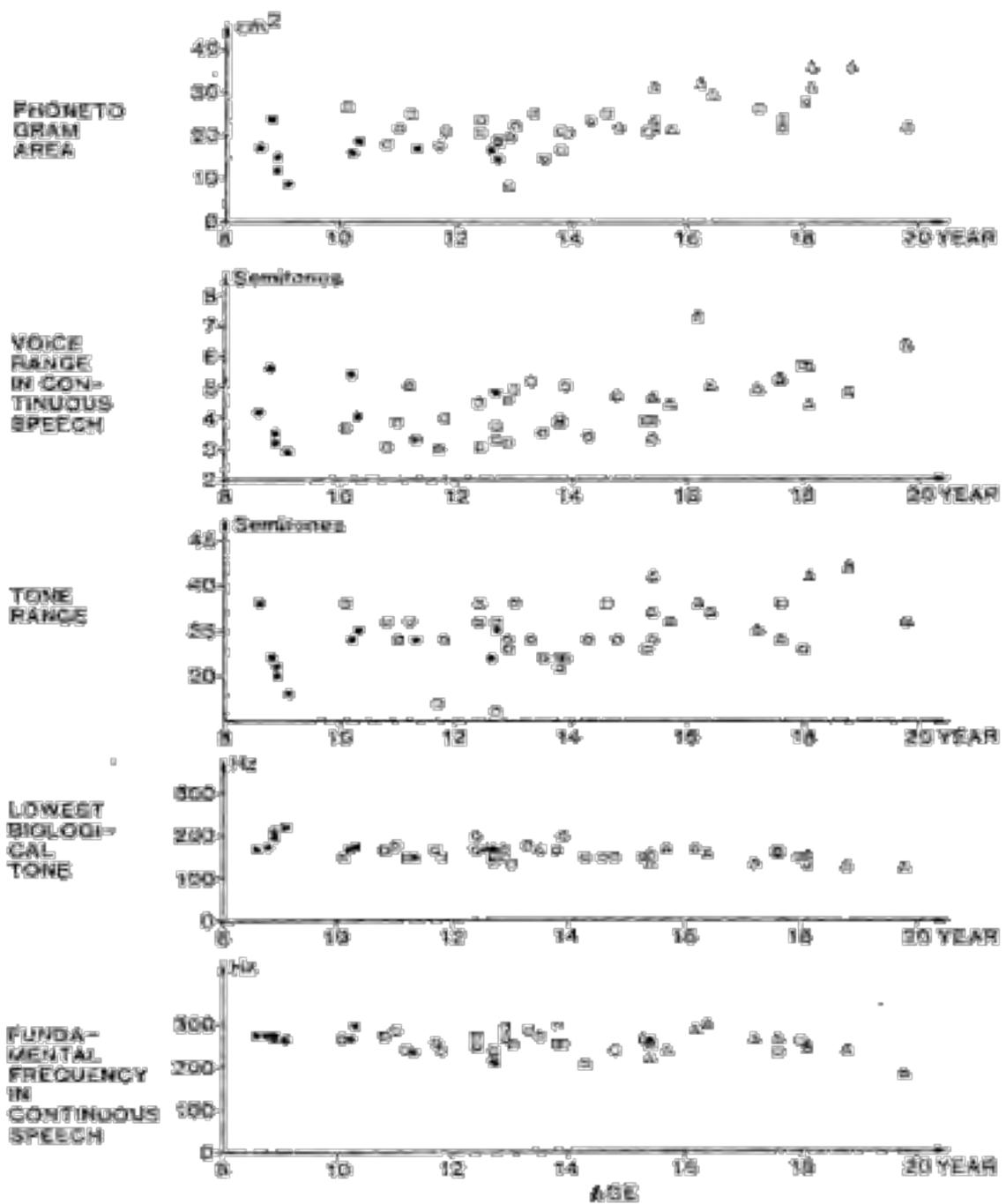


Figure 9 - The fundamental frequency in girls related other voice parameters

### **1.4.5. Longitudinal study**

We have made a longitudinal study of three boys from the end of the 7th school year before 6 weeks summer-holiday till the end of the 8th school year with phonetograms and hormone analysis every second month, in all 6 examinations for every boy. The six phonetograms of one boy were compared with the average of the time left in the choir and the time after for all 3 boys.

We used our computerized averaging program. Boy 1 was measured with phonetography and blood sample five times before he was excluded from the choir, and the averaged phonetogram represented his pitch and loudness range during the singing period. A typical pubertal phonetogram showed thereafter reminiscent of the higher childish tones, but with reduced loudness range ("reduced strength") and clear changes in register positions.

The case in boy 2 is the opposite of boy 1. Already in the first phonetogram in the 8<sup>th</sup> school class a reduced loudness range was seen for high notes and a register shift was seen. 5 averaged phonetograms with a typical pubertal configuration showed reminiscent of high child registers and two beginning adult registers. Boy 3 had three phonetograms from the last time in the choir (and three following exclusion from the boys choir). A large amount of information is given by voice range profiles for semitone range, position of register change and loudness variations in their relation to frequency etc.

The exclusion from the choir occurred during the eighth school year in all three boys. The changes in this year were not age related.

## **1.5. Discussion**

### **1.5.1. Electroglottography**

Titze (1994) did not recommend electroglottography as a standard measurement method. The reason was that the method can be developed further (Herzel et al. 1994). Still electroglottography is considered a useful test in voice evaluation. Dejonckere (1995 at the 1st World Conference of Voice) suggests that for extracting fundamental frequency (FO) the waveform in most cases is considerably simpler to use than the acoustical waveform: intonation contours and especially distributions of FO can be used to describe normal and abnormal voice characteristics.

We also examined the positive parts of the electroglottographic cycle divided by the whole cycle as suggested by Frokjaer-Jensen (1983), and Hacki (1989) in our choir studies. A separate work of its change in puberty was under consideration, confirming other results of differences in impedance between the

registers in these normal voices (Lecluse 1977). But even if electroglottography is the most stable and simple measurement for fundamental frequency in running speech in a reading situation e.g. as illustrated by Chan (1994), there seems to be an agreement with Titze (1994) that standards for the electroglottographic curve are not necessary yet – e.g. long-winded discussions of the Frokjaer-Jensen apparatus (1968) turning the curve of the closing phase down and the laryngograph (Fourcin & Abberton 1971) up recalls the humorous aspect. That discussion of the curve ended with the multichannel phonetograph by Rothenberg (1992). The use of the electroglottographic curve for understanding nonlinear chaoslike changes in voice disorders shows that the method will follow voice research into neurobiology. The synchronization with stroboscopy will, of course, ensure the relevant concepts (Hertegard & Gauffin 1995).

### **1.5.2. Fundamental frequency**

The discussion of fundamental frequency is interesting. To some extent the different approaches to the phenomenon depend on the researchers' background. Pitch is a perceived tone property of central importance in both speech and music, defining pitch physically by the frequency of the fundamental, the lowest spectrum partial, being mainly controlled by the vocal folds but influenced by subglottal pressure (Sundberg 1994). The pitch measured with electroglottography is well defined, based on the measurement of the primary larynx sound, at best combined with flowglottography. The discussion with the physicists, especially the critics among them, for our part resulted in an exclusion of the pitch in a study of patients with brain damage (Pedersen 1995). This illustrates the need for interdisciplinary standards discussions in clinical pathology.

The laryngeal perturbation analysis suggested, among others by Karnell (1991), that jitter and shimmer seems necessary in less well defined groups than the singers in this material. Another point of discussion is the test utterance. Titze suggests that clinics and laboratories could benefit from some consensus.

Titze suggests several non-speech and speech utterances (1994). From a medical point of view, the comment could be that voice is only one of many biological parameters, and that the use of test utterances in a reading situation is well established (Kitzing 1979).

Therefore, we chose only to use two parameters: the mean fundamental (FO) and its range (FO range) during reading of a standard text, as suggested by the International Phonetic Association, (1964) in this study.

### **1.5.3. Voice range profiles / phonetograms (V)**

The international voice range profile has been chosen for quantitative measurement of voices (Airaier & Klingholz 1993, Pedersen 1991 a,b). The method has been accepted as the method to be used as a basis of further voice testing (Int. Fed. Oto-Rhino-Laryngol. Societies (Wendler 1989)), Int. Ass. of Logopedics and Phoniatrics, and first World Conference of Voice (Schutte 1995)). (synonymous: phonetogram, Stimmfeld, voice profile).

The reason for the basic status of phonetography is the graphical presentation of a person's maximal and minimal vocal capability concerning fundamental frequency range and dynamic range on several standard pitches chosen (Schutte 1995).

Referring to the problem of what fundamental frequency really is, the best description is achieved by comparing the measurement set-ups on the market. This comparison was carried out in a group of researchers who themselves are constructors. The apparatus discussed were the Key-elemetric model 4326 (1993), the Phonomath (1988) by Homoth, and the Phonetograph 8301 by Voice Profile (1984/1995).

They all measure RMS with a resolution of 1 semitone based on an inbuilt tone generator during intonation of a sustained "ah" with a distance of the microphone from the mouth of 15 cm (Key-elemetrics) to 30 cm (Phonomath and Phonetograph 8301).

The loudness measurement apparatus available on the market are supplemented with Stimmkonditionsmesser by Meditronic SMO3, Bruel and Kjaer sound pressure level meter type 2236 and to some extent Soremed, (EVA work station). Earlier Vilkman et al. (1986) had an apparatus available for a short time, and Schutte has tried to adapt software for sale based on advanced Windows software. The intensity measurement was only dB(A) weighted in the Phonetograph 8301 equipment available in 1984, but a new one with both dB(A) and dB(C) has been available since 1995. Key-elemetric and Phonomath have built-in possibilities for dB(A) and dB(C). Soremed, EVA workstation uses dB(A) or dB(C). Stimmkonditionsmesser, SMO3, from Meditronic uses dB(A) and the most advanced sound pressure level meter type 2236 from Bruel and Kjaer uses dB(A) and dB(C) (+/- peak) connectable to a computer for calculations.

To some extent, the above-mentioned set-ups illustrate the problems of phonetography and their solution: dB(A) and dB(C) can be used if information is given of the measurement method. Differences are seen in the lowest frequencies. Supplementary measurement of peak values and singing formants is desirable. The rescaling method for phonetography was compared with the absolute frequency measurement method by Sulter et al. (1995), this shows the superiority of the latter in relation to e.g. Coleman et al. (1977), due to the

increased absolute frequency related information e.g. for registers. They also emphasize the use of the phonetogram area as a value independent of plotting factors. A discussion of registers was made by Svec and Pesak (1994) and Vilkmán et al. (1995). Measurements based on a set-up which includes high-speed video-filming elucidates the changes in registers in puberty, Probably will it be the routine not only in our clinic.

#### **1.5.4. Voice range profiles in puberty**

The phonetograms (voice range profiles) give a more stable basis for comparison with other phenomena of puberty than the range of semitones alone. This was illustrated in our comparison between Copenhagen singing school and Thomaner Choir, Leipzig, showing high SPL ranges for high notes in Thomaner choir sopranos (Behrendt & Pedersen 1989).

The highest semitone is to our knowledge dependent on the training situation and singer selection, though probably not the lowest semitone, which was significantly related to SHBG (Pedersen & Møller 1987).

In their examination of voice range profiles in ten year-old children the references include few analyses by other researchers, (McAllister et al. 1994). The study included the one by Flatau and Gutzmann from 1905 which still is true for semitone ranges in school children. But our study has resulted in a possible standard for voice range profiles for normal children. Bohme and Stucklic (1995) conducted a study of untrained children from 5-14 years of age where a standard voice range profile for 7-10-year-old girls and boys was established. The difference of around 5 dB(A) maximal loudness in favor of the boys was the same as in our material. No area calculation was made. In puberty they refrained from averaging voice range profiles due to the inter individual variations, which serves to illustrate our use of trained (well-defined) children to understand the difference between the genders in puberty. Bohme and Stucklic regret that the voice range profiles were unstable in 5-6 year olds. Methods (like child audiometry) still need to be developed for rehabilitation of children with hearing disabilities.

The musicality of the children in the Copenhagen singing school is not especially high (Copenhagen city area). Still, the pupils have a consciousness of their voices which is dependent on voice education. Pahn and Pahn (1991) made a relevant program both for testing vocal musical conscience, corresponding to ours, and for speech. From a pediatric point of view, and even in the ear-nose-clinic, the survey of yearly change in voice range profiles, can help in differentiating pathological from normal voices as described by Pedersen et al. (1985) and Bonet and Casan (1994). Voice range profiles can be used as an objective tool for

documentary of healing of voices. The division into singing voice categories can be used by singing teachers to evaluate the future position of a child based not only on semitone range in singing, especially the lowest tone but also on loudness range. The greatest loudness range should also be decisive for the category of the child.

It is an easy task to analyze testosterone and estrone as a routine in hormonal and pubertal stage disorders and compare them with voice range profiles, especially the lowest semitone and the area in semitones x dB(A), before possible voice therapy for changing of voices is planned.

### **1.5.5. Fundamental frequency (FO)**

The statistical calculations for prediction of voice changes not only with testosterone and estrone but also SerumHormonBindingGlobulin in puberty seem to be of interest. The presented calculations are based on the BMDP statistical program used in a stratified study confirmed in boys and girls by a stratified longitudinal study. Although the results in our study seem obvious, a larger longitudinal study might refine our understanding of the function of SHBG as a carrier of testosterone. The carrier globulins for hormones are currently being intensively examined, and the results can be a basis for further studies (Strel'Chyonok & Vihko 1985). Tobias et al. (1991) found androgen induced masculinization of tension and fiber type of the larynx in frogs differing from fiber recruitment. No such studies seem to have been made in humans. But the results indicate that the development is still more complicated. Longitudinal studies are immensely labor intensive (citation: Hollien et al. 1994). Hollien et al. made a study on adolescent voice change in males (1994). The lack of hormonal analysis is a problem and this is from a pediatric point of view also the case for lack of pubertal staging. The results are interesting, but therefore not usable in a medical setting, also because the study ceases at the age of 15.5 years. The measurement of fundamental frequency was made electronically by reading of a text with a standard procedure as in earlier done in our cases.

Hollien et al. refer that the voice change beginning at mean 233 Hz at 13.4 years (SD 10.4 months) was generally preceded with a varying pattern of fundamental frequency for at least 4 months succeeded by a decreasing slope for at least 6 months. In 34 boys with complete analyses (Hollien et al. 1994), the end of the change at mean 122 Hz could be defined as that point occurring at the (lowest) fundamental frequency immediately preceded by a period of frequency stabilization - lower than 140 Hz on average 18 months later. The study by Hollien et al. (1994) can also be used to confirm the results showing the voice to be a necessary part of defining puberty.

Comparison with other studies is a problematic task. Even Hollien (1994) uses for the first months in 1990 manual measurements of oscillographic traces obtained from a phonellograph. Herein lies the problem of exact comparison with earlier studies especially in females where our exact electroglotto-graphic results show the fundamental frequency range (FO range) in running speech in a reading situation as the new interesting parameter. Still there seems to be consensus now that in speech fundamental frequency (SFF) must be measured continuously for several seconds, and that the fundamental frequency variation in ongoing speech is a necessary parameter in females. Russell et al. (1995) find standard deviations of SFF in adult young females in the same range as in our post-pubertal girls. In terms of hertz, the results found by Hollien et al. (1994), possibly geometrical means, are interestingly higher in boys during puberty than later on, which of course can be related to the non-singer background. A coordination with examination of females would have been of great value in his examination.

#### **1.5.6. Perspectives**

Our study can be used as an updated version of earlier voice research in puberty based on technical advances and new hormonal knowledge. It is a necessary task which hopefully will be never-ending (Weiss 1950).

The future perspectives are technical: using the programs for example referred to at the International Computer Music Conference (Siegel 1994) in our biological voice research, and genetic: studies of musical vocal gifts (Sataloff 1995). A combination is for example ongoing research of voiceprint and genetic studies, perhaps also in puberty. For the biological understanding of voice, it remains necessary to discuss results with experienced singing teachers, a relevant place is the International Voice Teachers Conferences (Pedersen .2009 and 2011), because the musical quality of the best trained voices remains a guideline for biologists. It has, however become easier to separate the technical/ biological side of voice training from the musical side than has previously been the case, making it a simpler task to define pathology, also in puberty.

### **1.6. Conclusion**

Phonetograms / voice range profiles based on db(A) give a stable knowledge of total semitone ranges, supplemented with exact measurement of maximal and minimal loudness. This can be used to compare the voice function in puberty with other biological phenomena.

Based on the video films findings, the electroglottographical waveform reliably gives the vibratory frequency of the vocal folds for fundamental frequency in running speech in a reading situation.

The voice range profiles / phonetography and electroglottography for voice fundamental frequency analysis compared with other biological parameters gives supplementary understanding of the voice development during puberty:

The voice range profile develops during puberty in the two sexes in nearly the same way, with a narrowing of the voice range profile area located at the pubertal register shifts, especially from 13.5 to 14.5 years of age, the greatest shift occurring in boys.

The decrease in fundamental frequency in both sexes is related to testosterone and estrone. For boys the mean fundamental frequency in a reading situation (FO) is related to testosterone, and for girls the tone range, in particular, in a reading situation (FO range) is related to estrone. This parameter should always be combined with mean fundamental frequency and fundamental frequency variation measurements in both sexes, but especially in girls.

The development of the voice in puberty is significantly related to the rise of testosterone in boys and estrone in girls with extraction of age. The drop in sex hormonal binding globulin for testosterone (SHBG) predicts the fall in the mean fundamental frequency (FO) in a reading situation (when under 219 Hz) in boys in puberty stage II-IV, where testosterone is increasing. In girls the fall in the mean fundamental frequency is predicted by both the increase of estrone, estronesulphate (E1SO4) and the semitone range in running speech in a reading situation.

Sexual ripening varies, qualitatively and quantitatively, in boys and girls, but occurs for voices at 13.5 to 14.5 years of age. Lack of adequate apparatus for measuring the differences and similarities may account for the lack of girls' choirs over the decades. A voice identity based on phonetograms and fundamental frequency (FO) as well as biological range (FO range) in running speech probably constitute an implicit knowledge for an optimal development of the musical expression in girls as well as in boys .

## **1.7. Bibliography**

### **1.7.1. Abbreviations and definitions**

DHEAS dihydroepiandrosterone sulphate

EKG electroglottography

E1 estrone

E2 estradiol

E1SO<sub>4</sub> estrone sulphate

F0 mean fundamental frequency in running speech in a reading situation of a standard text

F0-range frequency variation in semitones in running speech in a reading situation of a standard text (= voice range)

LTAS long term averaged spectrogram

Octaves German description: C-c-c l-c2-c3,

American: C3 = c, C4 = c1, C5 = c2 etc.

SHBG sex hormone binding globulin

ST semitone in the octave, defined from the phonetogram

SPL sound pressure level

Total pitch range the range from the lowest to the highest semitone in the phonetogram

### **1.7.2. List of Separate Communications (in Thesis Oulu 1997)**

I Pedersen, M.F. (1977) Electroglottography compared with synchronized stroboscopy in normal persons. *Folia Phoniatr.* 29: 191-199.

II Pedersen, M.F., Møller, S., Krabbe, S., Bennett, P. & Svenstrup, B. (1990) Fundamental voice frequency in female puberty measured with electroglottography during continuous speech as a secondary sex characteristic. A comparison between voice, pubertal stages, oestrogens and androgens. *Int. J. Pediatr. otorhinolaryngol.* 20: 17-24.

III Pedersen, M.F., Møller, S., Krabbe, S. & Bennett, P. (1986) Fundamental voice frequency measured by electroglottography during continuous speech. A new exact secondary sex characteristic in boys in puberty. *Int. J. Pediatr. otorhinolaryngol.* 11 21-27.

IV Pedersen, M.F., Møller, S., Krabbe, S., Munk, E. & Bennett, P. (1985) A multivariate statistical analysis of voice phenomena related to puberty in choir boys. *Folia Phoniatr.* 37: 271-278.

V Pedersen, M.F. (1993) A longitudinal pilot study on phonetograms / voice profiles in pre-pubertal choir boys. *Clin. Otolaryngol.* 18: 488-491.

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# Cases of voice development in children, advances in evidence based standards Part 2

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## 2.1. Core Message

Based on our earlier findings of the development of voice with measures of phonetograms and fundamental frequencies during childhood, we have tried to update our knowledge: High speed films and pathology measures of the mucosa of the upper airways are presented during adolescence. Further systematic randomized trials should be made to understand the hormonal development of voice.

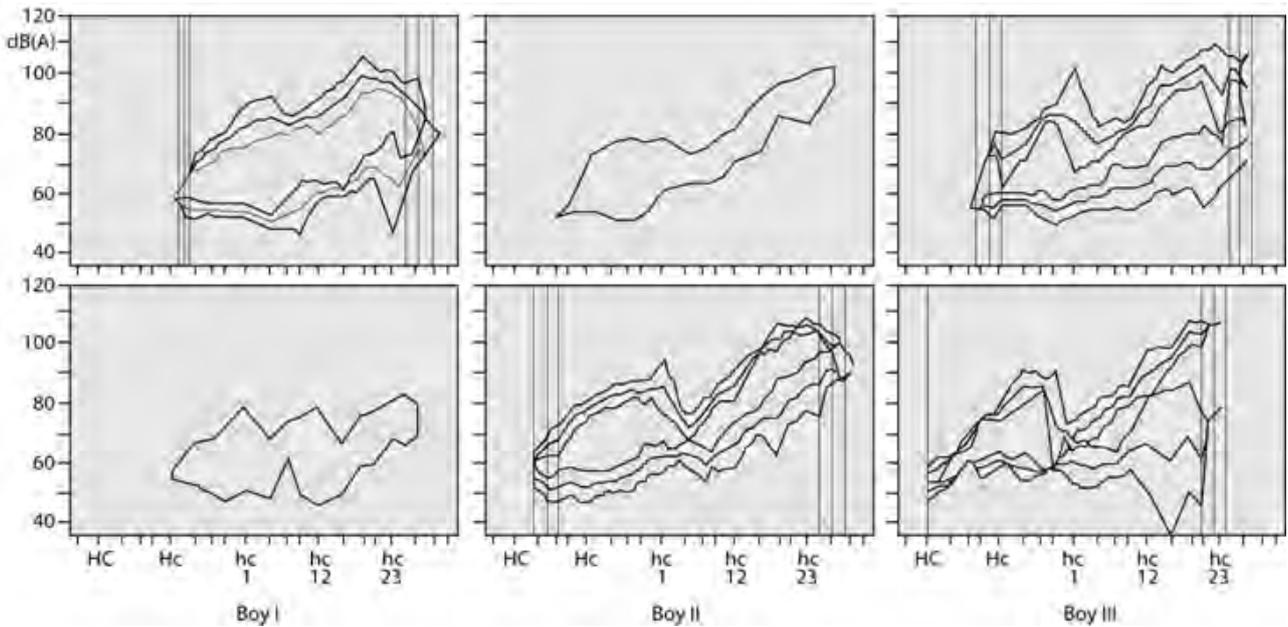


Figure 10 - Three boys with phonetograms in the eighth school class during puberty

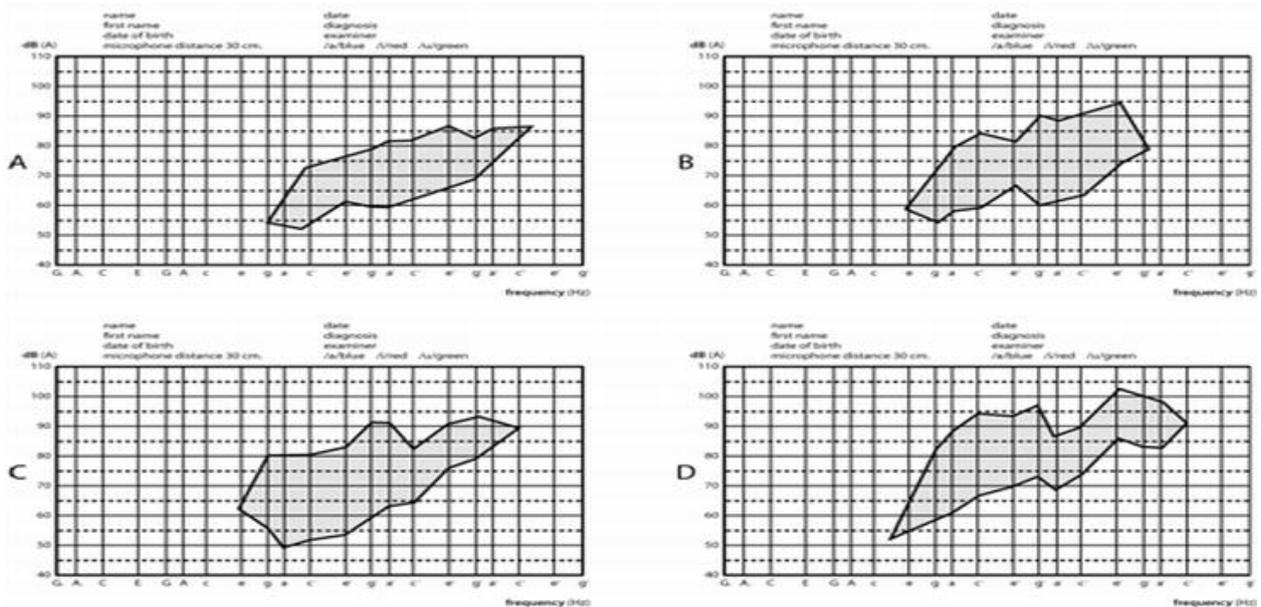


Figure 11 - One girl phonetogram during development, A before training, a pubertal register shift is seen in picture D

Based here on it has been interesting to start using high speed films in childhood and puberty. 6 cases of pathological adolescent voices, have been compared with the normal population referred to in part 1, especially in adolescence. An evaluation of pathology was made with high speed films, and treatment was carried out related to upper airway mucosa disorders, and pubertal stage.

High speed films (Wolf Ltd.) contained the possibility to make 2000 or 4000 pictures per second of the larynx, with the vocal cords for a maximum of 2 seconds (Bonilha H, Deliyski D 2008). A registration can be made of the vocal cords with electroglottograms and acoustical curve online, as well as the right and left vocal cord moments at the wanted places. A survey with kymography can also be made online. The measurement includes segmentation for slow motion of the vocal cords, where register shifts can be demonstrated. A quantitative measure is possible of the closure between the vocal cords in the front, center, and rear parts (Pedersen M, Munck K (2007), Pedersen M (2008)).

Diagnostics of upper airway mucosa disorders in childhood include especially examinations for allergy and infection which can be hard to differentiate from technical faults as well as development of voice. Based on measurement of fundamental frequency and phonetograms it is possible to evaluate the pubertal stage and to some extent the technical stage, so that hormonal measures can be left out.

Treatment of allergies and infections in children does not differ from adults, yet it is more important for young singers to understand and be treated because of the increased risk of technically faulty singing due to the developmental aspects. In the presented youngsters antihistamines of the newest generations, fexofenadine (Compalati E. et al. (2011)) and antibiotic macrolids (Piscitelli SC, Danziger LH, Rodvold KA (1992)) were used with great effect. Of course more specific disorders must be focused upon also.

## **2.2. Cases**

In the following, cases of different pubertal individuals with mostly common vocal pathologies are presented. Each case is described with diagnosis and treatment, including lifestyle advice. Two observations with two weeks interval have been done. Parameters in the measurements included: high speed films, with segmentation of vocal cords, electroglottography (EGG), acoustical - kymographical curves, and phonetograms. The patient was often treated with fexofenadine, local cortisone and ephedrine just to reduce reactive edema of the mucosa when voice rest was not possible, due to concert demands.

### 2.2.1. Case 1

This boy is a 17 year old male who sings rock music. He has had symptoms of hoarseness for 6 months. His diagnosis is singing in mutation, with functional laryngitis as a result. The laboratory examinations showed normal results. The patient was helped through the stress with an antihistamine (fexofenadine, 2 tablets daily of 180 mg), a steroid (budesonide 2-3 inhalations, 1-2 times a day of 200 micrograms) and ephedrine (duact 240 mg) when necessary. The singer was advised to sing carefully in the two low registers. Objective findings in the larynx were: Irregular borders of the vocal cords suggesting 4 fundamental voice areas, slight edema of the surface, especially on the right vocal cord, and injected arytenoids. The phonetogram analysis showed 4 registers. A "tuning" of the acoustical curve is shown at 509 Hz and 186 Hz.

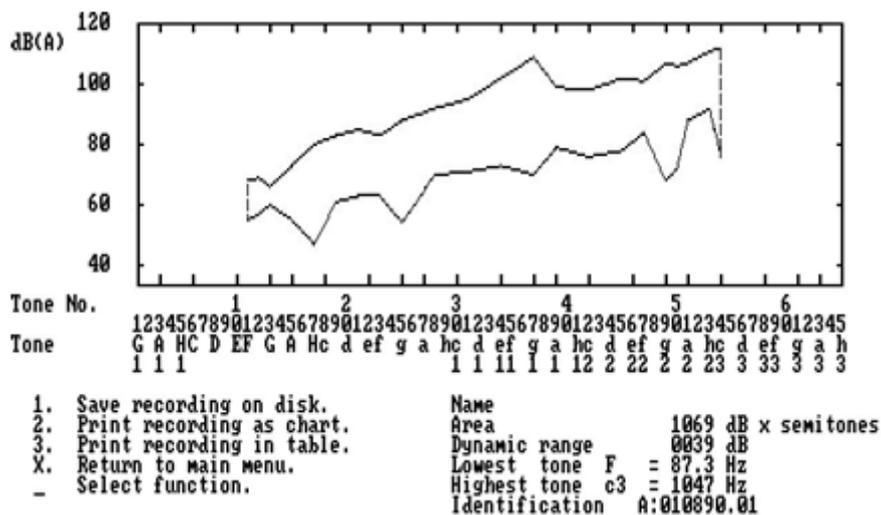


Figure 12 - This is a phonetogram of the 17 year old male singer

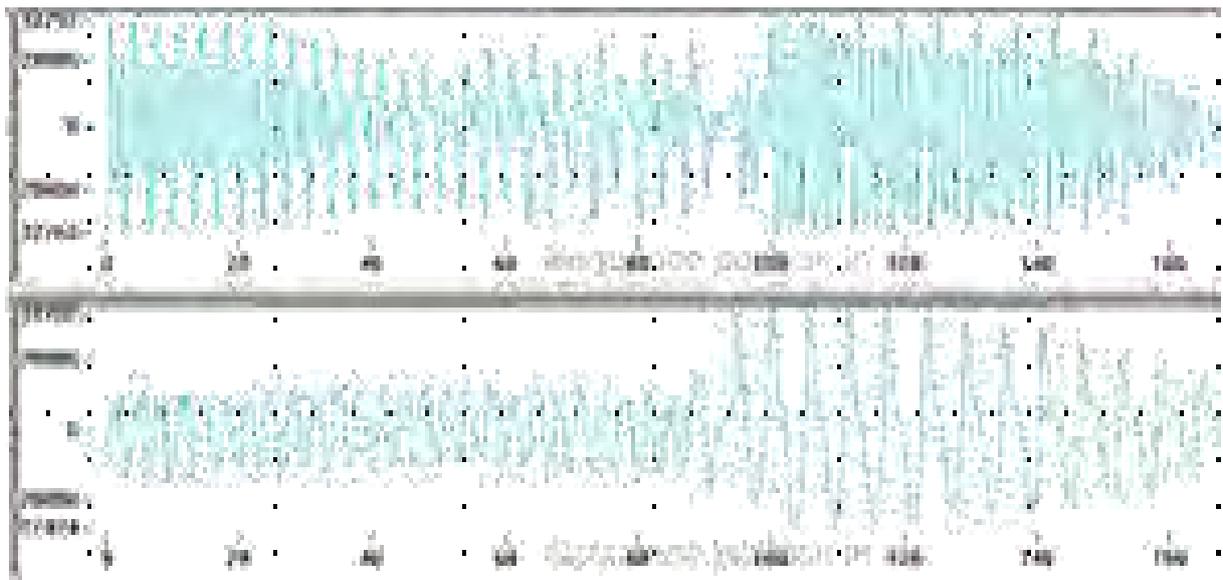


Figure 13 - High speed measures. The analyses were made in the middle of the vocal cords with 4000 pictures/second. The acoustical change is related to the “tuning” of the vocal tracts. The “tuning” was not seen on the EGG at 509 Hz. Acoustically, around 10 cycle

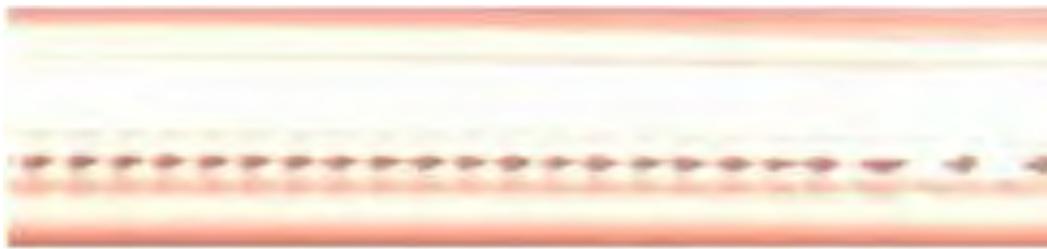


Figure 14 - The kymographic film corresponds to the electroglottographical picture.

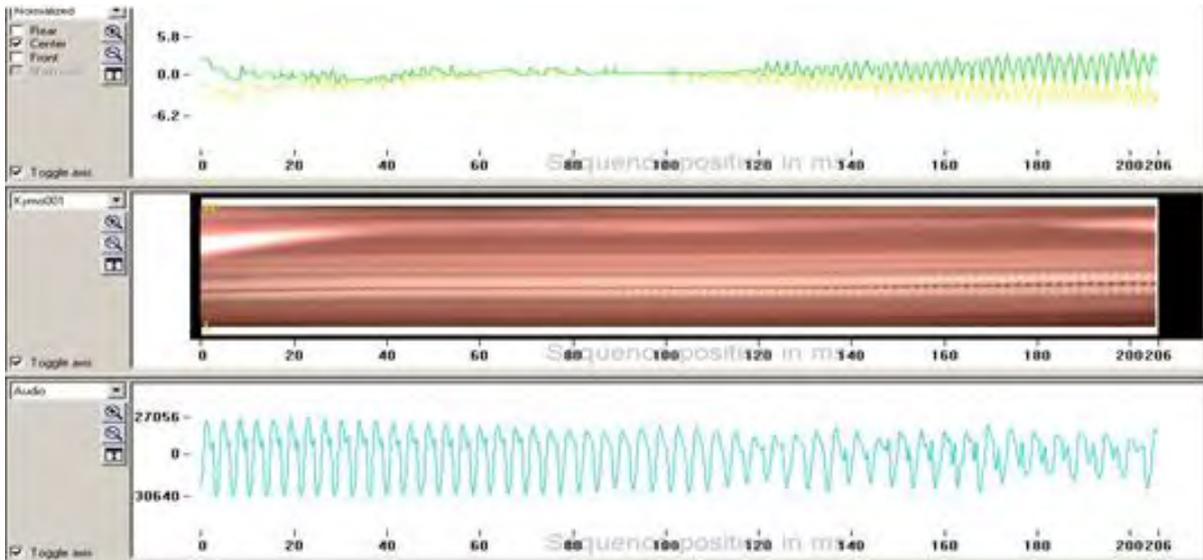


Figure 15- Overview at 186 Hz, showing the movements of vocal cords in the center of the vocal ridge, kymography, and the acoustic measures

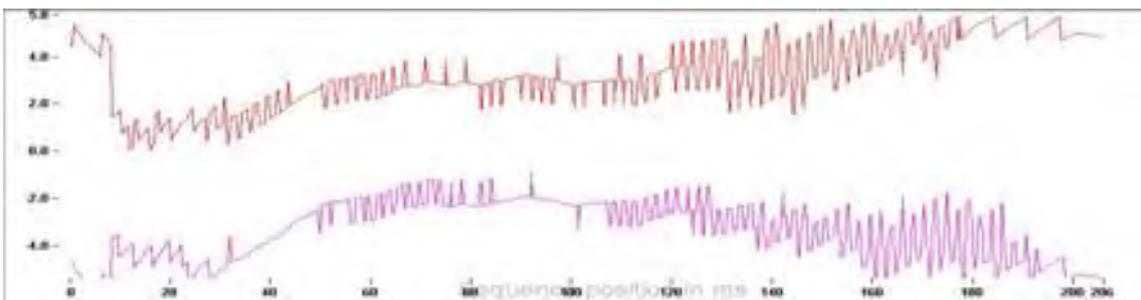


Figure 16 - The front part of the high speed film shows no connection between the vocal cords of 186 Hz

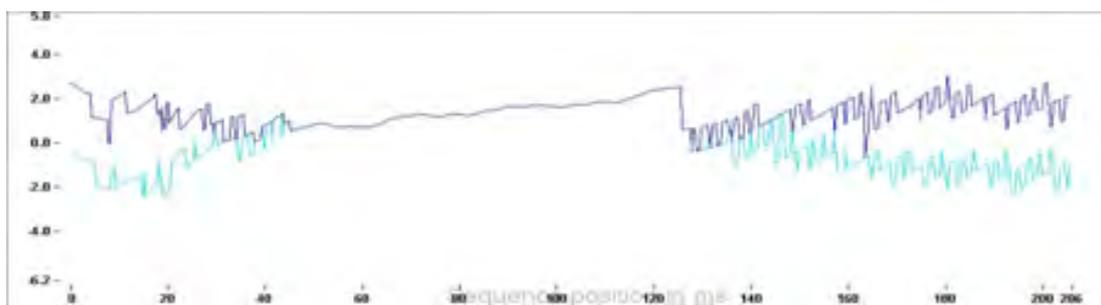


Figure 17 - The rear part of the high-speed film shows unstable connection between the vocal cords, in the rear parts

### 2.2.2. Case 2

This client is a 13 years old male, singing at the Rhythmical Conservatorium in Copenhagen. He has had symptoms of a cold including infectious coughing for 1 month. The diagnosis given was chronic laryngitis and rhinitis. The laboratory results were normal. The patient was treated with antibiotics (azithromycin, 250 mg daily for 6 days), antihistamine (levocetirizin 5 mg daily), and adrenalin derivate (terbutaline, 0,5 mg daily). The singer had no technical problems when singing, so no instructions were given. The objective findings were slightly swollen mucosa in the whole larynx.

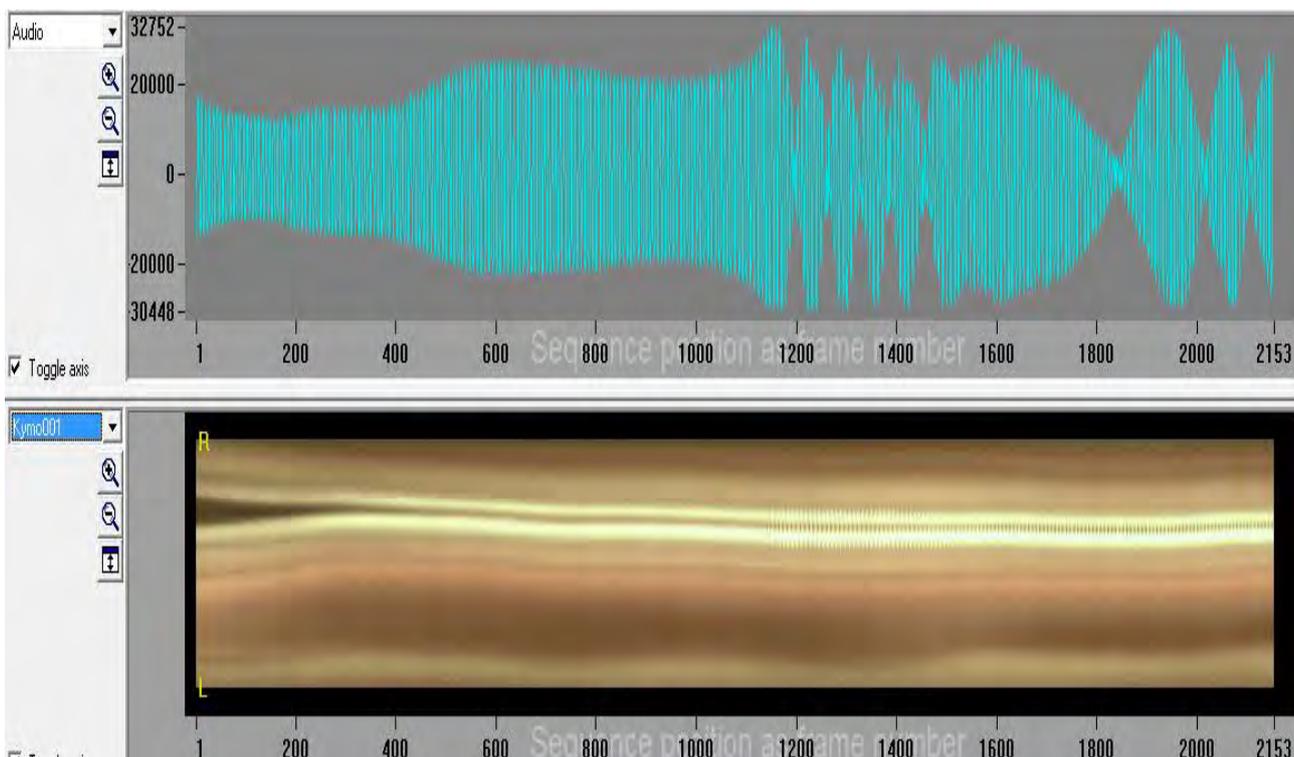


Figure 18 - Acoustical measures, kymography, both with some regularity

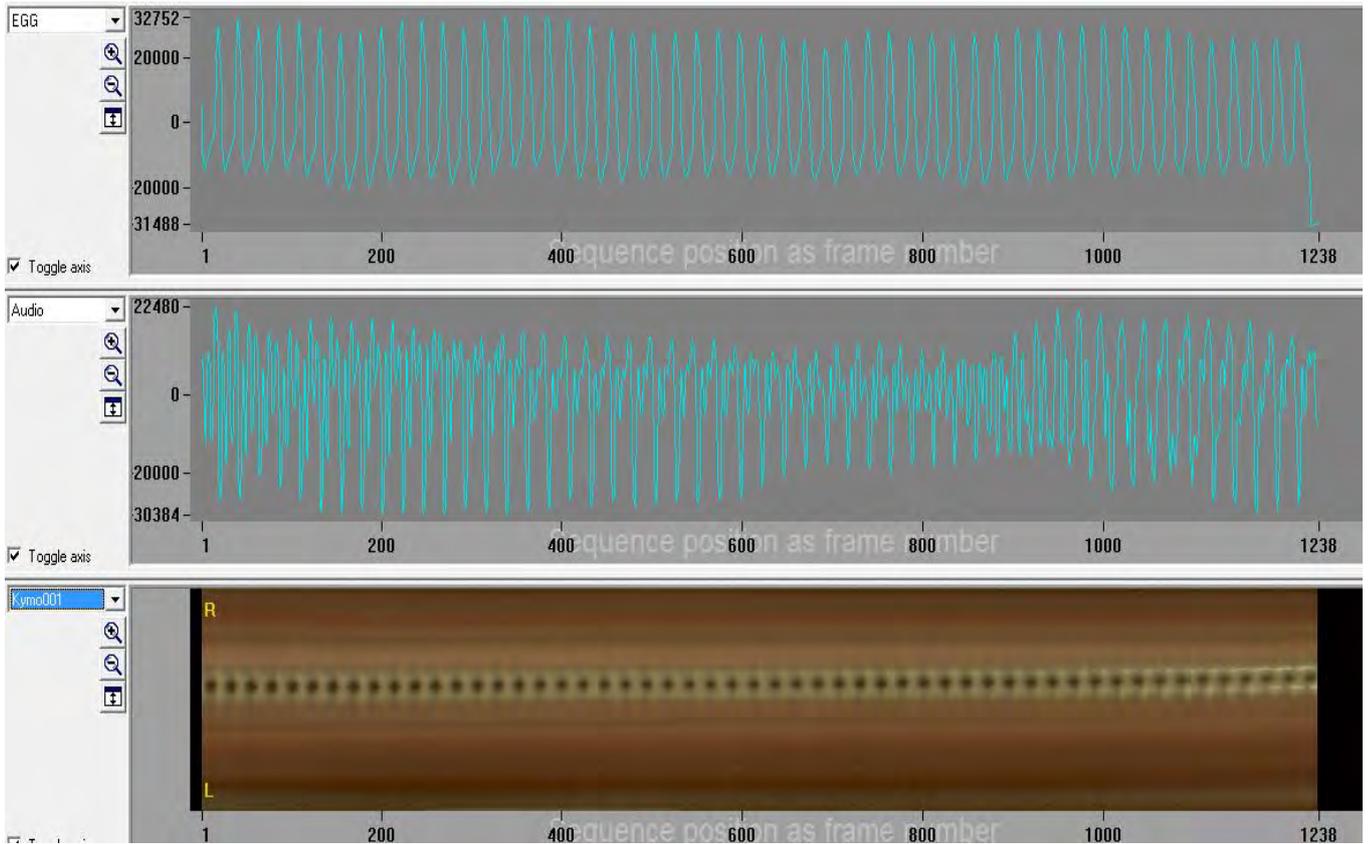


Figure 19 - Electroglottography (above), acoustical measures (centre) and kymography (lowest). The Electroglottography is more regular than the acoustic curve



Figure 20 - Picture from the high speed film of the larynx (left), and the fundamental frequency (right)

### 2.2.3. Case 3

The boy is a 13 years old male, with a background as a soprano soloist at the Royal Danish Boys' Choir in Copenhagen. He has suffered from chronic rhino – sinusitis due to the indoor climate in his school and mucus in the throat for 3 months. He has sung at several concerts during this period. The diagnosis was chronic rhinitis (X-rays of sinuses were normal) and chronic laryngitis. Laboratory results showed vitamin D

insufficiency (39 n mol/L). The treatment given was local steroid drops in the nose (fluticasone, 100 micrograms 2-4 times a day), antihistamin (loratidine, 10 mg once a day), and antibiotics (azythromycin, 200 mg daily for 5 days). The problem was not technical, but he was advised not to press the voice – which he did.

The findings for the larynx were swollen vocal cords with edematous nodules, and swollen nasal mucosa. The analysis from the high speed video at adduction and abduction was especially interesting. The phonetogram measure showed a higher dynamic area at the second examination.

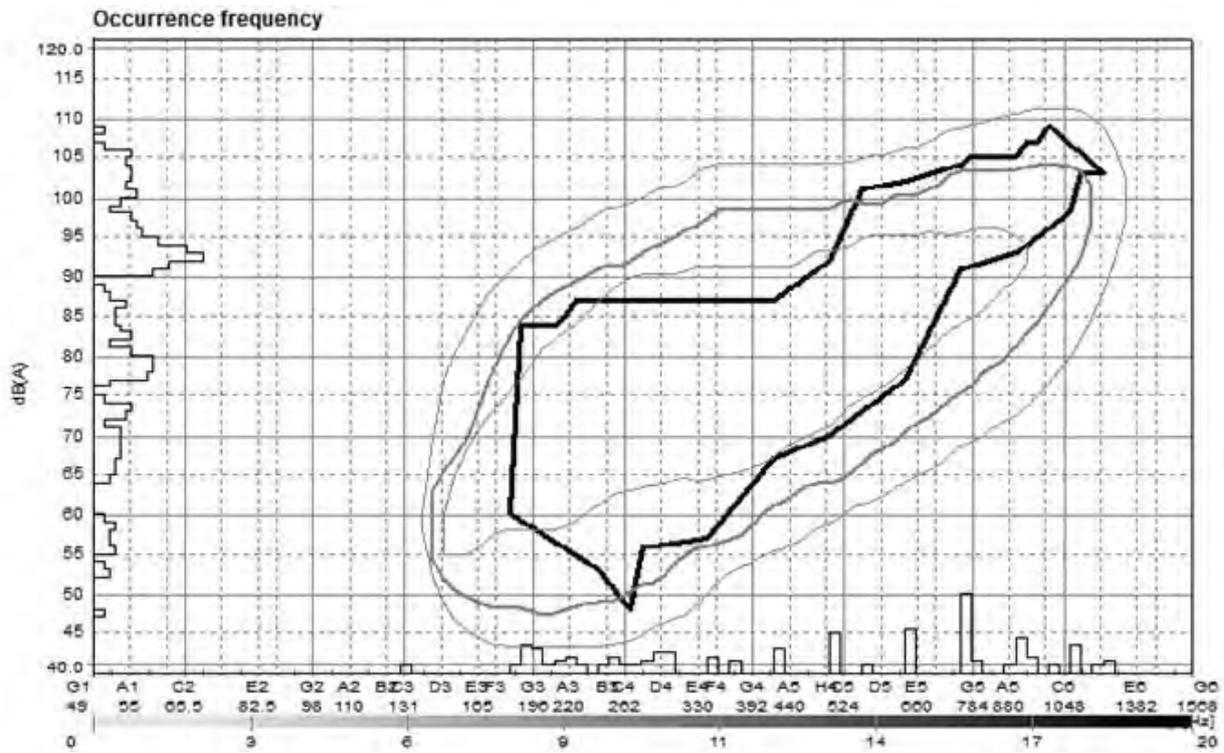


Figure 21 - The phonetogram at the first examination

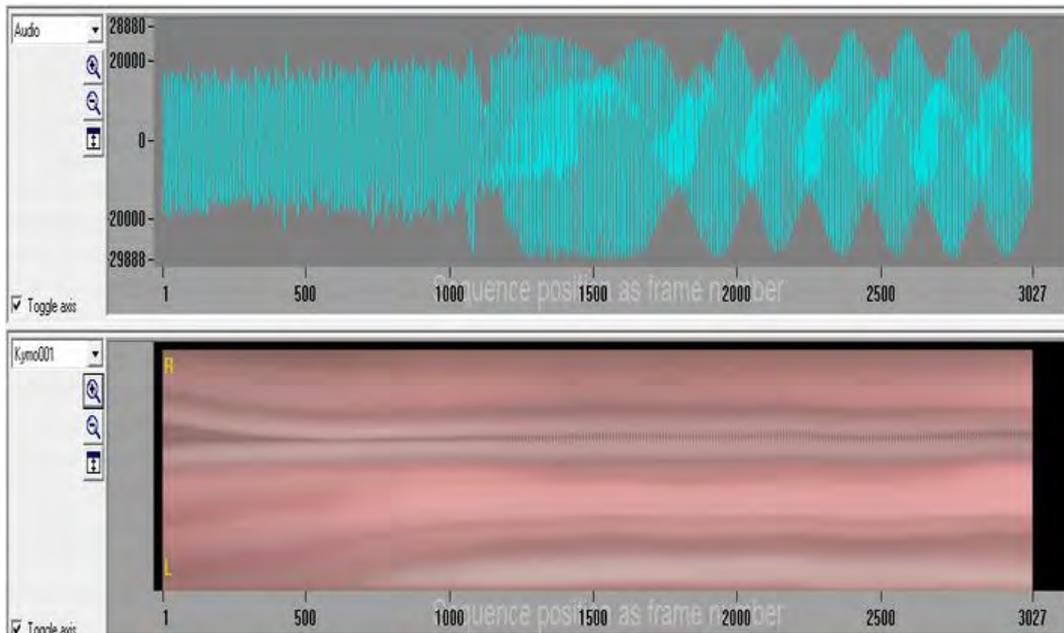


Figure 22 - Acoustical analysis and kymography. High speed measures at the first examination showing the intonation begin spectrum

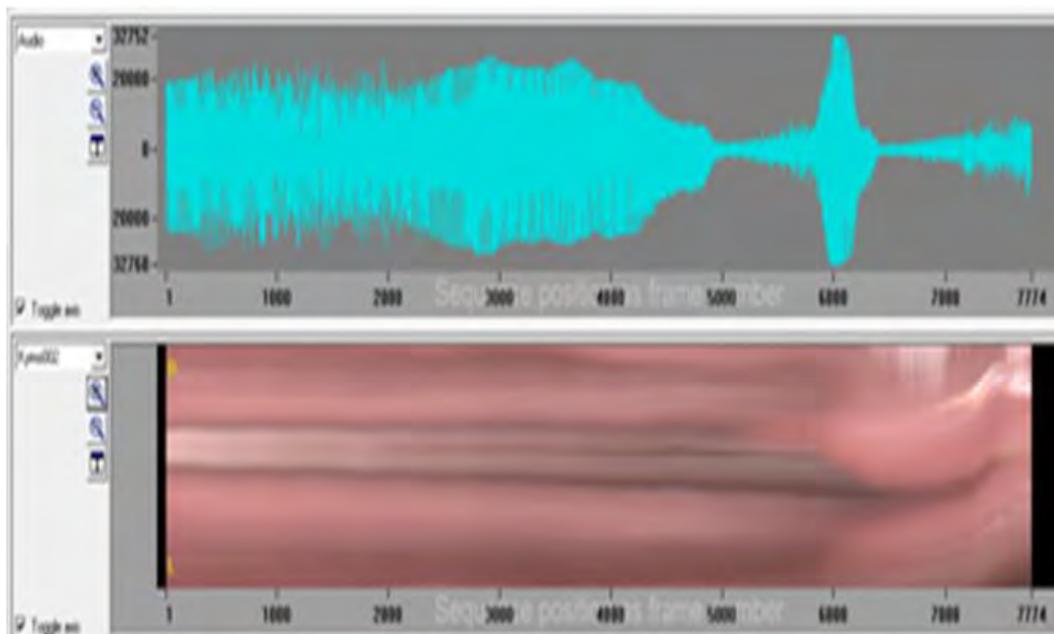


Figure 23 - Acoustical analysis and kymography showing pressing of voice. High speed measures at the end of intonation

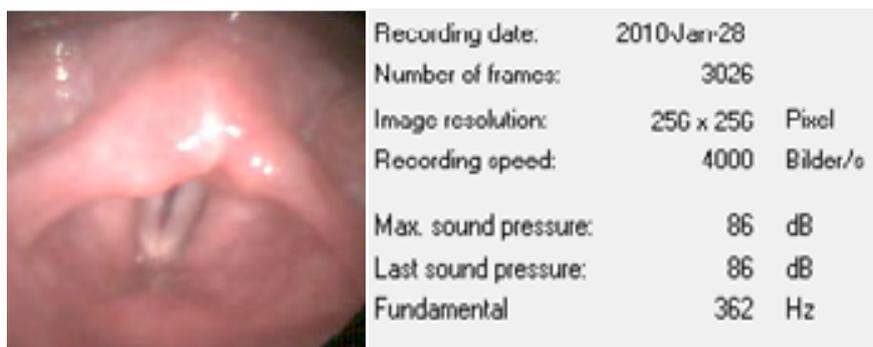


Figure 24 - Picture from a high speed film of the larynx at the first examination with edema of the arytenoids and slight vocal nodules (left). Fundamental frequency (right)

### 2.2.4. Case 4

This child, a 14 years old female pupil at the Copenhagen Singing School sings in the girls' choir. She had a sore throat for 6 weeks before she came to the clinic. The diagnosis was tonsillitis (may be provoked by a documented positive helicobacter bacterial infection). Several allergies were found, including: birch, grass, flowers, dogs, cats, wheat, peanuts, soya beans, and mould. Helicobacter was IGA positive. The helicobacter infection was eradicated after the results of IGA were received after one week. Firstly fexofenadine (120 mg, one tablet daily) and azythromycin (250 mg, daily for 6 days) was given as treatment. Secondly helicobacter eradication was done. The pupil was advised to sing with care. The high speed film showed that the vocal cords moved *with* each other before treatment. After treatment, the high speed film showed that the vocal cord movements were normalized, moving towards each other. Phonetogram and vibrato were unchanged.

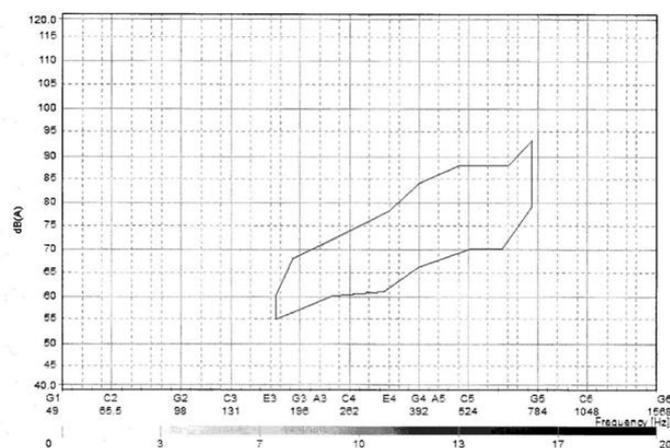
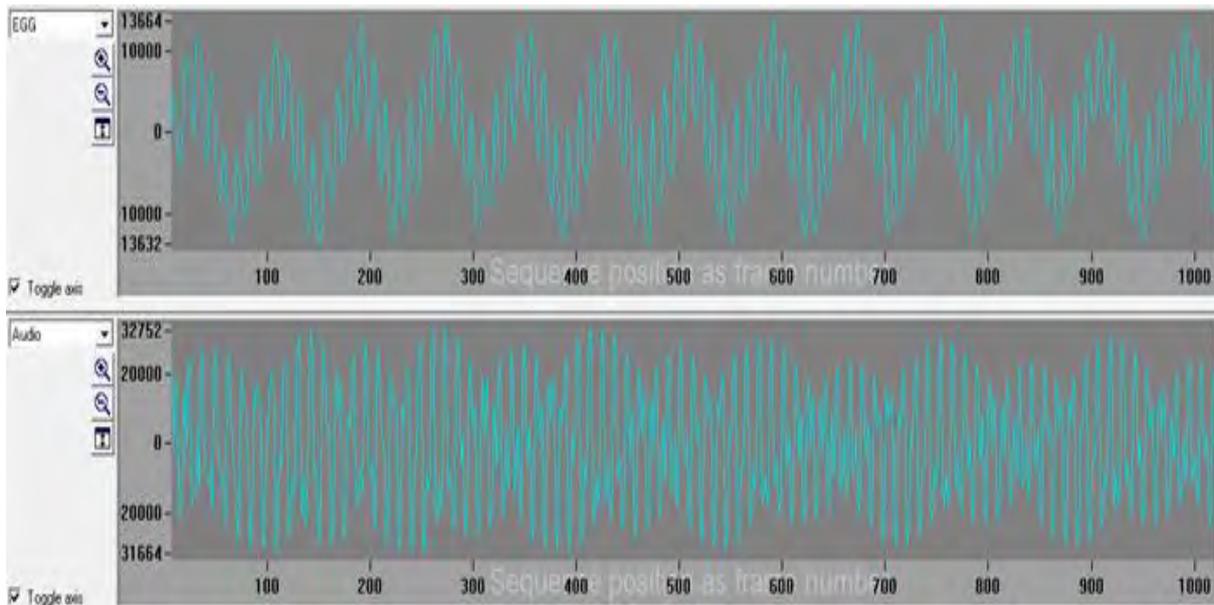
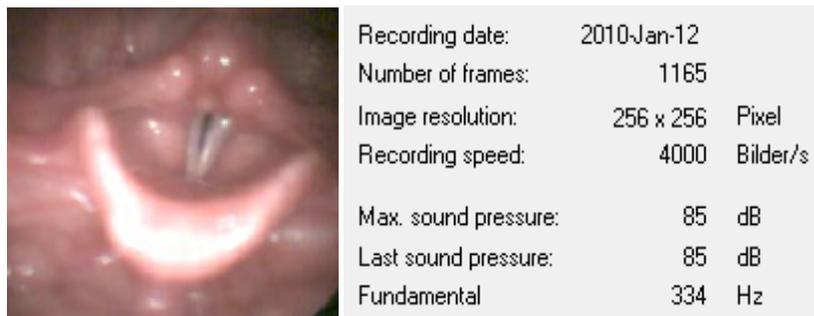


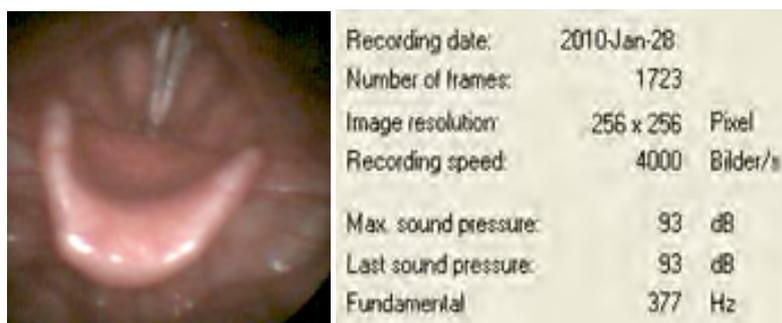
Figure 25 - The phonetogram before treatment



**Figure 26 - The vibrato at the level of the glottis as well as the resonans area. High speed measures of Electroglottography and acoustical analysis before treatment showed regular moves**



**Figure 27 - Picture of high speed film of the larynx, showing edema at the rear part of the larynx (left). Fundamental frequency before treatment (right)**



**Figure 28 - Reduction of the edema in the rear part of the larynx of treatment (left). Fundamental frequency after treatment (right)**

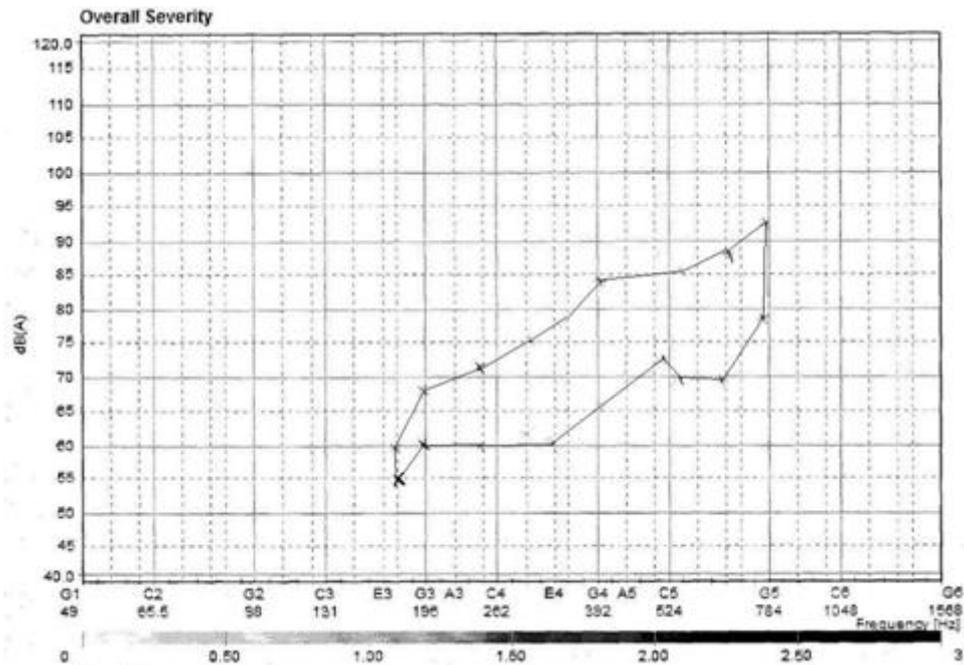
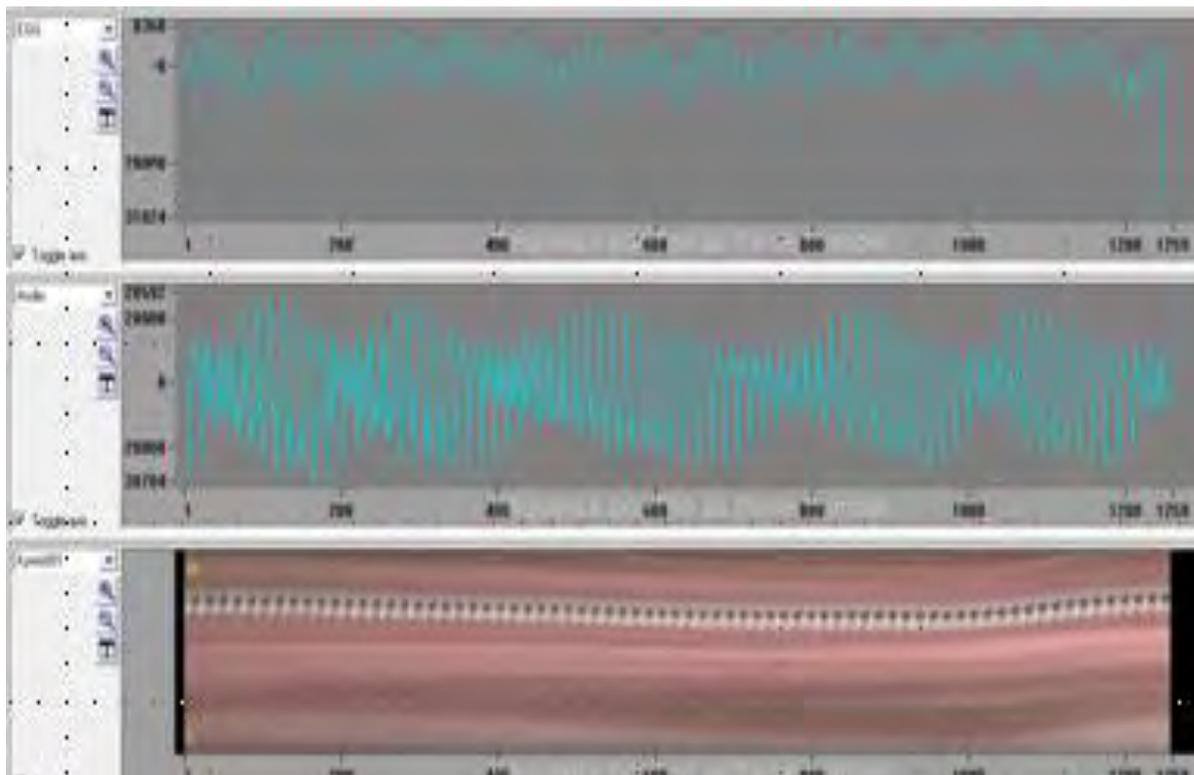


Figure 29 - Phonogram after treatment

### 2.2.5. Case 5

This young female is a 17 years old amateur singer in a rock band. Her symptoms were hoarseness and a weak voice; this has persisted for 2 months. The diagnosis was Hashimoto thyroid infections (and direct trauma during a boat trip in Africa). Ultrasound measures showed enlarged thyroid gland on the right side, with adenoma-like processes. Laboratory results showed High TSH (Thyroid Stimulating Hormone) levels (135 MIU), and lowered Mannose-Binding Lectin indicating reduced activity of the innate immune system. For treatment, the following was given: azythromycin (500 milligrams daily for 3 days) and fexofenadine (180 milligrams once a day). The patient was referred to an endocrinological department upon arrival of the results. Partial recurrent paralysis on the right side of the vocal cords, with reduction after two weeks was found.



**Figure 30 - Electroglottography, acoustical analysis and kymography. High speed measures showing a rather well regulated voice with vibrato at EGG and acoustical level**



Recording date:	2010Jan-15
Number of frames:	1258
Image resolution:	256 x 256 Pixel
Recording speed:	4000 Bilder/s
Max. sound pressure:	77 dB
Last sound pressure:	71 dB
Fundamental	233 Hz

**Figure 31 - Reduced movement of the left vocal cord (left). Fundamental frequency (right)**

### 2.2.6. Case 6

This 16 years old female amateur singer had a chronic cold and glands on both sides of the neck, she was under treatment for bulimia. The neck lymph nodes had been painful for 4 months. The treatment for bulimia had lasted for 2 years. Ultrasound examination showed several pathological, enlarged lymph nodes, the biggest one measuring 3 x 1, 3 cm on the left side. CT scan of the sinuses showed edema of the maxillary sinuses, taking up 50% of the volume on both sides. The laboratory results were normal. The patient was

first treated with fluticasone drops in the nose (200 micrograms x 4 a day), azythromycin (500 milligrams daily for 3 days) and fexofenadine (180 milligrams once a day), after the results of the X ray, additional treatment with clarithromycin (500 milligrams twice a day for 7 days) and amoxicillin (1000 milligrams for 7 days) was given. The objective findings in the larynx were normal mucosa and functional pressure especially of the false vocal cords on high speed films.

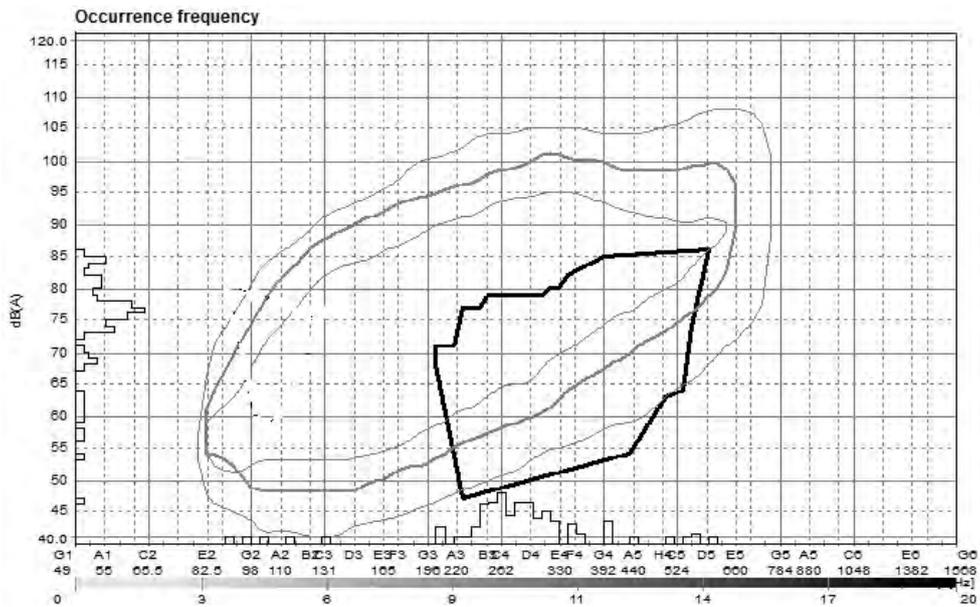


Figure 32 - The computed phonetogram, reduced area

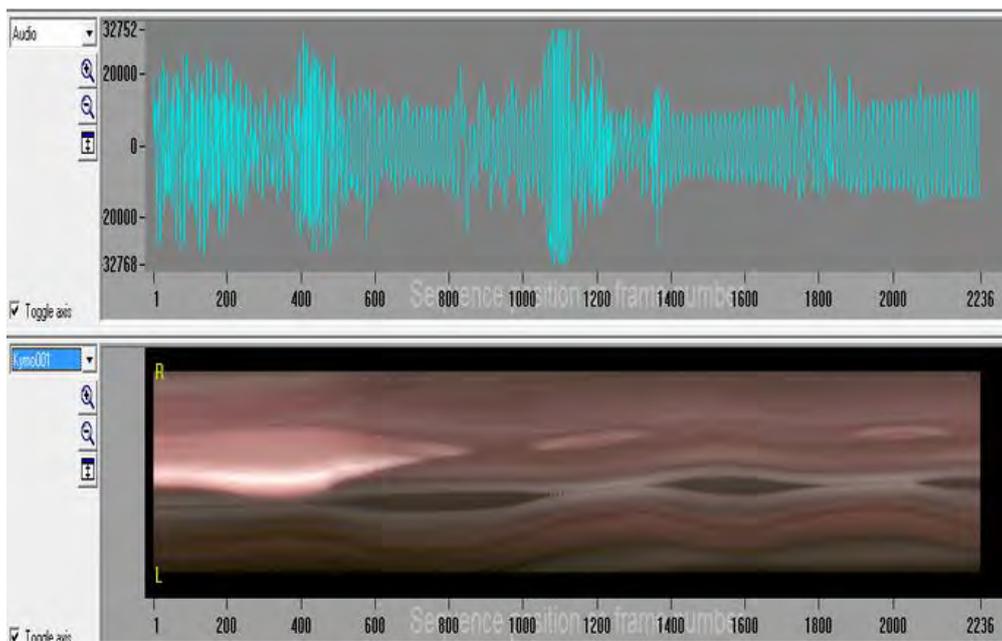


Figure 33 - The acoustical analysis and kymography before treatment, showing a pressured voice

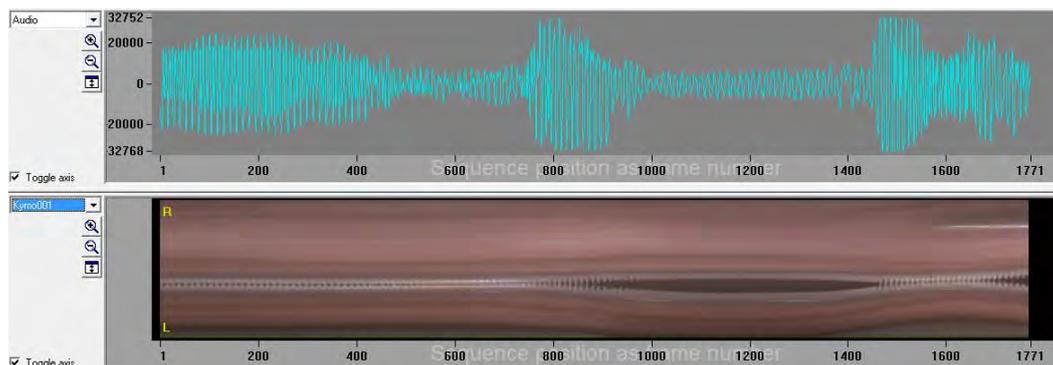


Figure 34 - The acoustical curve and kymography after treatment, showing a slightly reduced pressure

Recording date:	2009-Dec-04	Recording date:	2009-Dec-11
Number of frames:	2235	Number of frames:	1770
Image resolution:	256 x 256 Pixel	Image resolution:	256 x 256 Pixel
Recording speed:	4000 Bilder/s	Recording speed:	4000 Bilder/s
Max. sound pressure:	79 dB	Max. sound pressure:	87 dB
Last sound pressure:	78 dB	Last sound pressure:	83 dB
Fundamental	313 Hz	Fundamental	287 Hz

Figure 35 - Fundamental frequency and intensity before treatment (left), and after treatment (right)



Figure 36 - Overview of high speed film after treatment

## 2.3. Results and Conclusion

It is now possible to differentiate between normal voice development and pathological voices in youngsters. Normal development shows well-defined changes per year in phonetograms and also in singing categories. With high speed films supplemented with phonetograms, the pathological mucosa of the larynx is better differentiated and can be visually compared online with eletroglottograms, acoustical curves, and kymographic movement of the vocal cords in the front, centre and rear parts. The treatment of pathology of

the vocal cords during childhood is easier nowadays with high speed films, also in singers during adolescence. Prophylactic pedagogic courses in vocal understanding and the awareness of boundaries within register-shifts should be considered. The strain of developing child voice often has its roots in wrong vocal technique because of a lack of differential to pathology.

Phonetograms give the frequency and intensity borders of voices during development related to hormonal development. High speed films illustrate online pathology of the vocal cords also in children.

## **2.4. Acknowledgements**

Thanks to the students in the clinic especially Sanila Mahmood.

## **2.5. References**

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