Glottal frequency analysis

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Report of a method - Glottal Frequency Analysis - for on line registration of the mean, range and distribution of the voice fundamental frequency in continuous speech. The phonatory periods are detected electroglottographically and processed in a microcomputer (Intel 8080). The method is primarily intended for clinical investigations of phoniatric patients and for judging the effect of logopedic and laryngological therapy. Previous methods for determining the voice fundamental in speech are reviewed and problems in determining voice pitch are discussed. There is not always good correspondence between the vocal vibratory periods and the sensation of voice pitch. In the present method, period data irrelevant for pitch sensation are not allowed to influence the results of the frequency analysis. GFA-measurements and auditory judgements of voice pitch were shown to be highly correlated, whereas the voice range could be reliably determined only by means of measurements. Voice fundamental frequency data are given for 192 normal speakers and for 244 patients with voice disorders before and after different kinds of therapy. The influence of various external variables on voice fundamental frequency is reported. There were no differences of voice pitch between reading prose aloud and speaking freely, nor did the emotional character of a read text have any major influence on the voice fundamental frequency. By getting subjects to play a part in an aggressive dialogue the voice pitch was significantly raised and the range increased in comparison with reading neutral prose. After a series of field studies of occupational voice strain in places of work, 52 patients with disorders of voice function were subjected to a loading test where they had to compete with white noise. After reading aloud for 15 to 30 minutes very significant differences appeared after logopedic therapy as compared with before. A further development of the method is suggested to provide an objective measure of vocal condition in cases of suspected disorders of voice function in analogy with other loading tests used in clinical physiology.

Key words: voice pitch; speaking fundamental frequency; voice disorders; voice therapy; androgens; smoking; loading test voice.

Part one.

1. Introduction

The fundamental voice pitch of speech or, "speaking fundamental frequency" (SFF), conveys important linguistic as well as non-linguistic information. The linguistic information can be divided into segmental and suprasegmental. Segmental pitch information is used only in tone-languages, like Swedish, Norwegian or Chinese, which use differences of pitch as a distinctive feature between phonemes. Language-dependent suprasegmental pitch variations form the pattern of intonation. Also, a great deal of the non-linguistic information conveyed by the speech signal is expressed by variations of pitch. The speaker usually has more conscious control of his verbal than of this non-verbal communication. Non-verbal pitch cues commenly give information about the speaker, such as his mood and and his attitude to the present communication (para-linguistic information) or his age, sex, the condition of his speech organs, etc. (extra-linguistic information, speaker identity).

In clinical evaluations of the voice function the focus of interest is mainly on this later, extra-linguistic aspect of SFF. Therefore, methods to measure SFF developed in other fields of research are not necessarily applicable for use in speech clinics. Some examples are: intonation analysis in linguistic phonetics; pitch extraction for vocoders; and speech synthesis in technical acoustics. For a most detailed review of these aspects cf. Hess, 1983.

The aim of this study was to develop a simple and reliable method to measure criteria of the SFF, like the mean, the range and the distribution of frequencies, to be used by voice pathologists in a clinical setting. One important task was to show, that the measurements obtained with the new method compared with pitch estimations by a group of experienced listeners (validity) and that the differences between different measurements of the same subject were acceptable (test-retest reliability). Finally, the suitability of the method in practical work had to be tested.

The need for a clinical method to measure SFF has been documented by an enquiry performed by the Hungarian phoniatrician, J. Hirschberg, presented at the Congress of the European Union of Phoniatricians in Weimar (GDR), 1977. Out of twenty-one answers from voice pathologists all over Europe, twenty found SFF measurements to be the most important electroacoustic method of investigation to be developed for routine use in voice clinics.

2. Pitfalls in SFF analysis.

The most obvious way to measure SFF is by low pass filtering the microphone signal. However, this signal may be entirely void of energy at the level of the fundamental even if the human ear has no difficulty to estimate the fundamental pitch. For example, it is a common experience to identify the sex of a speaker in a telephone conversation by his fundamental pitch, even if the acoustic information is missing in such signals below a frequency level of about 300 Hz. In direct acoustical analyses of the voice, the intensity of the fundamental may be reduced because of deviant voice function (hyperfunctional or strained quality) or it may be masked by vocal tract resonances.

One particular diffficulty are so called octave jumps, seen in intonation curves when pronouncing vowels with a low frequency of their first formant, like [i:] and [u:] ($F_1 \cong 300$ Hz). In such cases, the low pass filter analysis wrongly detects the first partial amplified by the resonators instead of the fundamental. This is easily seen in an intonation curve and the setting of the low pass filter may be adjusted accordingly, but in computerized analyses of the SFF distribution of speech such mistakes are difficult to recognize.

A method to avoid these difficulties is to base the SFF analysis not on the acoustic signal but on its counterpart, the vibratory frequency of the vocal folds. A well-known method to detect the vocal fold vibratory frequency is by electroglottography or electrolaryngography. In this method, a weak, high frequency alternating current between two metal electrodes on each side of the neck is fed through the tissues and modulated by the vocal fold vibrations. Contrary to an oscillogram of the acoustic signal, the resulting curve, called an "electroglottogram" or "Lx", shows just one conspicuous deflexion for each period, from which it is easy to measure the period length.

Pitch sensations are not entirely dependent on the frequency of the acoustic signal but also to some degree on its intensity. Therefore, high quality equipments for playing back music recordings have a device for so called loudness correction. However, this effect is not very conspicuous when estimating the pitch of speech. A close relationship between measurements of the vocal fold vibratory frequency corresponding to the fundamental frequency of the voice and estimations of the pitch level can therefore be expected especially in normal voices and in modal register. However, in low pitched creaky voices, also called "vocal fry register", most listeners experience a change of voice quality instead of lowered pitch, and they do not include their perceptions of creaky speech segments into their pitch estimation. The same applies for low frequency aperiodic segments of speech with a rough quality of voice. This seems to be a reason why analyses of the vocal fold vibratory frequency do not always show a strong correspondence with estimations of the voice pitch by experienced listeners, especially when pathological voice qualities are concerned. Automatic frequency analysis cannot differentiate between long periods, causing a sensation of low pitch, and vocal fry periods giving an impression of abnormal voice quality. If measurements of these vocal fry periods are included in the analysis this will result in too low values of average frequency to be representative of the estimated pitch of the voice (cf. fig. 1).

In certain cases of vocal fry, the glottogram is characterized by alternating higher and lower amplitudes. This doubles the detected period length and causes the resulting frequency measurements to be lowered incorrectly by an entire octave (fig. 2).

3. Method.

The method of SFF measurement presented here involves the detection of the vocal fold vibratory frequency by an electroglottograph. To avoid the above mentioned difficulties of acoustic F_0 analysis, i. e. to ensure that the vibratory frequency is representative of the perceived pitch, another step in the analysis had to be found. Thereby the undesirable low frequency measurements were discarded before the final analysis. The strategy to do this was to define the main distribution of the "raw" analysis and to accept all measurements within that range down to an accurrance rate of 2.5 percent (exclamation marks in fig. 1). Measurements below (and above) that limit were then discarded, even if they occurred more frequently (stars in fig. 1). The resulting "truncated" analysis was normalized and used as a measure of SFF.

The analyses were performed partly on a minicomputer (Nova 1220) and, as it became accessible, by a device based on a microprocessor (Intel 8080). In the later case they could be performed on line. In accordance with the pertinent literature, only two measures were chosen to characterize the distribution of the analyzed frequencies, viz., the arithmetic mean expressed in Hertz as a measure of central tendency and the 70 % range expressed in semitones as a measure of variance, nearly agreeing with the ± one standard deviation to be used in later versions of the method. Finally, the entire distribution of measured frequencies divided in classes of semitones was displayed. The frequency range was from 45 - 506 Hz. The "raw" analysis was based on 1000 period measurements, corresponding to about 10 -20 seconds of continuous speech, depending on the sex and thereby fundamental frequency of the speaker and the occurrence of silent segment in the speech sample. The measuring device, encluding the electroglottograph, the microprocessor and the display of the measurements, is called the Glottographic Frequency Indicator. In later versions it is refered to as the Glottal Frequency Analyzer (GFA).

4. Comparison between GFA-measurements and estimations of the mean SFF. Test of validity.

The aim of this investigation was to rule out significant differences between GFA-measurements and estimations of the mean SFF by a group of listeners. At the same time, the performance of this group had to be tested. The group of listeners consisted of twelve experienced voice therapists, four males and eigth females, whose hearing had been checked to be normal.

The investigation was organized in the following way. Tape recordings of 33 moderately dysphonic patients (16 females, 17 males) reading a standard text (The North Wind and the Sun, in Swedish) were copied on tapes in random order together with a number to identify them in the test protocol. The listening test was divided into two parts, carried out under a period of several weeks. To check the reliability of the listeners, five female and five male speakers were included in both parts of the test. When performing the SFF estimation, the listener could compare the recorded speech sample with a continuous tone from a sine wave generator. the pitch of which he could vary until he found it to agree with the mean SFF of the sample. The frequency of the sine wave as measured by a frequency meter with digital display was used to map the resulting mean SFF estimation. As it was expressed in Hertz, the frequency of the sine wave could be directly compared with the results from the GFA analysis. This analysis was made from an electroglottographic signal recorded on the second track of the tapes. The analyses were repeated three times to test the reliability of the system.

The statistical analysis of the results is thereby based on 132 (33 x 4) GFA measurements and 516 (43 x 12) estimations of the SFF. The general correlation between measurements and estimations was r = .98. The four male listeners showed a somewhat higher agreement with the measurements (r = .99) than their eight female colleagues (r = .97) and the correlation was highest for listeners of both sexes making pitch estimations on speakers of their own sex. After dividing the results into four groups, (female and male listeners who estimated the pitch of female and male speakers, respectively), a two-sided analysis of variance showed mean differences between measurements and estimations between -.3 semitones and 1.3 semitones. The general result was a non-significant difference of .42 semitones between the GFA measurements and the pitch estimations. This means that the pitch estimations were, on average, 2.5 % higher than the GFA measurements. This difference was considered to be without importance, so that the validity and reliability of the GFA method was considered as acceptable.

Considering the performance of the listeners, the comparison between the two pitch estimations of the same voices with an interval of several weeks showed a difference of only .5 % (s = 3.2 % using the method of paired observations. This surprisingly high test-retest reliability for the listeners as a group is of the same low magnitude as the variance between repeated GFA-measurements (.8 - 1.0 %). The correlation between the two pitch estimations was calculated to be r = 1.0. However, even if the listeners showed a very high test-retest reliability as a group their individual achievements differed considerably, one of them showing an average difference of as much as 14.6 % between both her pitch estimations. Another listener succeeded in reproducing his pitch estimation results with an average difference of only .3 %.

As could be expected, the pitch estimations varied to some degree with the quality and character of the voice samples. A closer analysis of this factor showed, that a correct pitch estimation is more difficult:

* at extreme levels of SFF;
* at wide ranges of the SFF;
* at bi- or plurimodal distributions of the SFF;
* in voices lacking sonority;
* and when the sex of the listener differs from that of the speaker.

5. Comparison between GFA-measurements and estimations of the SFF-ranges.

The psychoacoustic correlate to a narrowed SFF-range is monotony of speech. Sometimes stereotypisms of intonation are judged to be monotonous, but in this study the meaning of monotony is restricted to denote a narrowed intonation range. Measurements of monotony are of interest not only in phoniatrics and voice pathology but also in neuropsychiatry, as monotony of speech has been shown to be a characteristic of diseases such as: Mb. Parkinson, amyotrophic lateral sclerosis, pseudobulbar paresis, different kinds of encephalopathia, epilepsia, and myxoedema, as well as of schizophrenia and deep depression. In phoniatrics it is customary to make a distinction between the biological or total range, and the musical, i.e. the esthetically acceptable, range of the voice, besides the intonation range.

The measure of voice range chosen in this study is the 70 % range, excluding the extreme 15 % at each end of the SFF distribution which nearly corresponds with the measure of ± one standard deviation, the measure of range used in later versions of the GFA method.

To test the agreement between measurements and estimations of the SFF-range, the just described validation of measuring the mean SFF was combined with a similar test for range. As it was impossible to express the listeners' estimations of SFF-range according to an equally divided numerical scale, non-parametrical statistics were chosen to compare the results. The correlation for the entire material (identical with the mean SFF test just described) was r_s = .55. For male speakers, the correlation was r_s = .42 and for female speakers, r_s = .88. When repeating their own SFF-range estimations the listeners on an average achieved correlations of the same restricted magnitude. One third of the listeners did not even succeed in reaching a statistically significant correlation between both of their estimations of the SFF-range.

In conclusion, psychoacoustic estimations of the SFF-range were found to be inexpedient for the study. The only feasible way to establish the SFF-range is by taking mesurements in a similar way to the one presented in the GFA-method.

6. Normative data of the SFF mean and range.

Before and after certain types of neck surgery, such as thyroidectomy, it is common to check the function of the laryngeal nerves by indirect laryngoscopy as there is a certain risk of causing laryngeal paresis through surgical intervention. 151 females, aged 17 - 81 years (average

48 years., and 55 males, aged 19 - 73 years (average 47 years) had such pre- and postsurgical examinations of their larynx within an interval of 7 weeks, on average. These examinations were combined with SFF measurements by GFA, the normal condition and function of their larynx having been established. The average results including the variance ($\pm$ one standard deviation) can be considered as normative for speakers of Southern Swedish. The mean SFF for males was 110 $\pm$ 15 Hz and for females 195 $\pm$ 20 Hz. The average SFF-range was 6 $\pm$ 1 semitones for males and 5.5 $\pm$ 1.5 semitones for females. Compared to the extensive literature on the subject (cf table 1), these values of the mean SFF are somewhat lower, but not significantly so, whereas the values of SFF-range compare almost exactly with those found in other studies.

Reports on the SFF variance between individuals are sparse, and data about measurements of the same individuals on different occasions is almost non-existent. In this material, there was an average difference of 2 % between the two measurements of mean SFF, whereas the SFF-range differed by 4 % in the males and by 2 % in the females. This stability of SFF measurements from one occasion to the next in normal subjects is noteworthy, as it may serve as a background information when evaluating intra-individual changes of SFF parameters in connection with voice therapy or laryngeal surgery.

The only anthropometric or physiological factor earlier reported in the literature to correlate with the mean SFF is age, causing a drop of the mean pitch in both sexes, not only during mutation, which was not the concern of this study. Only in high senescence does the mean SFF increase again, more so in males than in females. The same tendency applied for the female subjects in this study, whereas the mean SFF was aproximately equal between various age groups of male subjects. As to the SFF-range, there was noted a tendency of widened range with increasing age in the female speakers.

To close this part of the study, it should be mentioned that SFF measurements are registrations of a behavior not to be mistaken for normative data in physiology. They are influenced by a number of factors such as smoking habits, social and cultural background, and the language of the subjects. *)

*) This part of the study has been extended at our laboratory with results showing similar tendencies, cf Pegoraro Krook, M.I., Speaking fundamental frequency characteristics of normal Swedish subjects obtained by glottal frequency analysis (GFA), 1986. Submitted for publication in Folia phoniat.

Part two.

7. The influence of different factors on the mean and range of the SFF.

7.1. Character of speech. Reading aloud vs. free speech.

It is a common experience from clinical tape recordings of patients reading a standard text, that in certain cases the reading is not similar to that of spontaneous speech. Therefore, some clinicians prefer to complement the tape-recorded readings by a sample of free speech. However, such procedures are difficult to standardize, making the comparisons between recordings questionable. Therefore, it seemed interesting to study how GFA-measurements obtained from reading aloud compared to free speech.

In the literature there are reports of both an increase and a decrease of the main SFF when reading aloud compared to free speech. However, the nature of these experiments have varied considerably, both as to the character of free speech and as to type of subjects participating. A survey of almost 400 speakers reported in these studies showed a tendency of an increased SFF of about 4 % when reading aloud compared to free speech.

In the experiment to be reported here, the subjects comprised of two groups of females, viz. 22 nursing students, aged 23 years on an average, and 13 patients examined before stumectomy (cf above), aged 42 years on average, all with normal conditions of their larynx and its function. The text read was The North Wind and the Sun. As a sample of free speech, the nursing students described their work in the hospital whereas the other subjects spoke about the standard text they had just read.

There was a considerable difference in mean SFF between the groups, with a value of 220 Hz for the nursing students and 192 Hz for the other subjects. This difference between the groups was thought to be caused by the difference in age and probably also by heavier smoking habits of the patients. This, however could not be substantiated in this part of the study.

In general, no significant differences were observed between the speech samples. The SFF mean and range for the entire group of subjects was respectively, 209.1 Hz and 4.4 semitones when reading aloud, and 209.5 Hz and 4.3 semitones, when speaking freely.

7.2. Emotional character of the text.

Literature on the influence of emotions on speech, and especially on qualities of intonation, is voluminous. In the reports it is not always clear whether the speech behavior of the subjects was influenced by differences of the content of speech or by changes in the mood of the subjects for other reasons, such as differences in the entire communicative situation.

For the GFA method to be useful in the speech clinic it had to be tested, if the SFF measures obtained from reading different kinds of text were comparable. Two narrative texts, both by the author Astrid Lindgren, which motivate an engaged, expressive style of reading aloud, were chosen to be compared with the emotionally more neutral Northwind and the Sun. One of the emotional texts was humoristic and quick, the other one was tragic and pathetic. The speakers were a group of 13 female students at a conservatory, chosen because of their expected higher degree of sensitivity to the emotional message of the texts, and a group of 18 female nursing students, expected to react more neutrally. No such expected difference of reactions between the groups was observed. Therefore, the results for the entire group of 31 female speakers, aged between 19 and 51 years, is reported.

Compared to the neutral standard text there was a minimal, but statistically significant, less than 2 %, decrease of the mein SFF when reading the tragic text. When reading the humoristic text, a 10 % increase of the SFF-range was observed. It was concluded, that the influence of the emotional character of each text on the measures of SFF was almost negligible. Therefore, the choice of text to be used in GFA measurements does not seem critical.

As a special observation from this part of the study, there was noted a 10 % difference of mean SFF between the conservatory and nursing students, the later showing the lower speaking pitch level. This difference was shown not to depend on the existing difference of age between the groups, but on their different smoking habits.

7.3. Communicative situation.

Many patients who suffer from voice problems show practically normal voice function when they are phoniatrically examined. Their problems often arise in situations of psychic stress or emotional engagement. To make statements, to argue and to persuade, is more taxing for the voice than smalltalk. The aim of the present part of the study was to try to change the situation and role of the speaker in a controlled way and to measure his reactions in terms of changes in SFF parameters. Twenty-two nursing students, aged 19 - 38 years, were asked to engage in a dialogue, where they acted as passengers in a bus and with an aggressive bus conductor questioning if they had paid the correct fare. The part of the bus conductor was recorded on tape by a male speaker and played back line by line to the subjects. By a special switch on the tape recorder, the bus conductor's lines could be made to fit very naturally in the dialogue. In this way the situation of conversation was exactly identical for all subject

The GFA measurements from the part in the dialogue were compared with the same subjects' readings of the Northwind and the Sun. The results showed an increase of 20 Hz of the mean SFF, equivalent to 1.5 semitones, as well as a 1.5 semitones increase of the SFF-range. These differences are highly statistically significant.

As it is impossible to measure the degree of emotional involvement of the speaker, the tape recordings were played back to a small group of listeners to evaluate on a three point scale the degree of involvement they experience when listening. The result of this enquiry showed a statistically significan increase of involvement experienced during the parts of the dialogue as compared with the readings of the Northwind. On the other hand, no positive correlation was found between changes of SFF parameters and changes in the degree of emotional involvement. In conclusion, it is speculated that increasing one's SFF level and range is but one of many ways to convey one's degree of emotional involvement in speech.

7.4. Effects of vocal exertion.

To raise one's SFF can be an effective way to make the voice heard, for instance when trying to penetrate environmental noise or holding command. However, continuous straining and vocal exertion frequently causes fatigue and irritation of the throat. Nursery school teachers, for example, often complain of such symptoms in connection with their professional activities.

The aim of this part of the investigation was to study the effect of vocal exertion on the SFF in a representative group of nursery school teachers. In a field study, 12 subjects, aged 24 years on average and all females, were recorded in their kindergarten during one week before beginning and after finishing their work. Even if some of them complained of vocal exertion during the period of working and two of them showed symptoms of vocal fatigue, no statistically significant differences of the SFF mean and range were noted in 55 pairs of observations from the 12 subjects between the morning and afternoon recordings. Whether the subjects' voice exertion had not been hard enought or if they had already rested their voice by the time they had arrived for the electroglotto-graphical and acoustical recording was not clear. However, in two other experiments the influence of voice exertion on SFF was obvious.

In the routines of the nursery school there was one activity which required the teacher to stay in the same room for an entire lesson. This was when teaching physical training in a gymnasium. Most of the teachers found this to be very tiresome to the voice. Acoustical and EGG recordings for later glottal frequency analysis were carried out by means of long wires that allowed the subjects sufficient freedom to move around.

In this way, it was possible to compare the SFF of four teachers when holding gymnastic lessons with their SFF when reading the Northwind in quiet surrounding. On an average, they showed a 50 % increase of their mean SFF and an almost 120 % increase of their SFF-range (from 3.8 to 8.3 semitones). These conspicuous differences proved to be statistically significant in spite of the very restricted number of subjects.

The second experiment involved a loading test of the voice. The subjects had to compete with 70 dB white noise when reading aloud for 30 minutes. Their SFF was analyzed on five occasions during the test, in silent surroundings immediately before the masking, and three times during the white noise. The results were expressed as percentage of difference relative the first reading in silent environment.

The results of eight of the nursery school teachers were compared with results from five experienced female voice therapists of comparable age and showed clearly differing tendencies both as to the mean SFF and the SFF-range. The teachers showed on average a 20 % increase of their mean SFF already after 15 minutes masking, and immediately after the test their mean SFF was still statistically significantly elevated by 7 %.

The voice therapists, on the other hand, showed a maximum increase in mean SFF during the masking first after 30 minutes and of only 8 %, and they recovered to almost their original level, when the masking noise stopped. As to the SFF-range, the teachers showed a statistically significant increase compared to their first reading in silence for all the four following recordings, whereas the voice therapists produced an unchanged SFF-range.

This part of the study was thought to have shown the suitability of the GFA- or similar methods to perform field studies of the SFF. On the other hand, reading aloud in silent environment did not always seem sufficient to test the condition of the voice. The favourable results of the loading test pilot encouraged further experiments which will be described in the last section.

8. SFF measurements in clinical cases of dysphonia.

Altogether, in 244 clinical cases of either functional or organic dysphonia, glottal frequency analyses were carried out before and after therapeutic intervention. The cases were divided into four groups, functional dysphonias, benign lesions of the larynx, (pre)cancerous lesions, and virilization from hormone treatment.

The group of voice disorders without organic pathology of their larynx consisted of 69 females, aged 37 $\pm$ 16 years, and 36 males, aged 39 $\pm$ 12 years. Their initial SFF mean and range was practically identical with the "normal" figures given earlier in this report (part 6). After about three months of voice therapy, a minimal but significant decrease of the mean SFF in females and a slight widening of the SFF-range, measuring half a semitone, for both sexes, was observed.

The group of <u>benign organic lesions</u> comprised only cases where the microstroboscopic examination had shown the lesion to interfere with the vibrations of the vocal folds. The group consisted of 46 females (age 43 ± 10 years) and 45 males (age 44 ± 14 years). The females' diagnoses were polypoid degeneration (29 cases), polyps (8), intubation granuloma (1), cysts (2), and nodules (6). For the males, the diagnoses were marginal oedema (12), polyps (27) and cysts (6). The male subjects showed no difference of their SFF measures from the presented "normal" values and microlaryngoscopic resection of their lesions caused no conspicuous change. The same was true for the SFF-range of the female subjects. Their mean SFF, however, was significantly lowered to 170 Hz before surgery, which caused a statistically significant increase of their pitch level by 11 % and thereby a normalization. The earlier mentioned lowering effect of tobacco smoking on the mean SFF was also substantiated in this group of subjects. One important fact, established by this part of the investigation was that the GFA method of measuring SFF criteria is also stable enough when the voice quality is "organically" rough, i.e. characterized by irregular low-frequency vocal fold vibrations interfering with the SFF analysis.

17 males with <u>leucoplakias</u> of their vocal folds and 10 males with laryngeal <u>cancer</u> in early stages formed the third group of clinical cases. No significant differences were observed compared to the normal values reported in part 6, between leucoplakias and cancer, or before and after microlaryngoscopic excisions of the laryngeal lesions.

The subjects of the fourth group were 21 females, aged 55 ± 5 years, with a lowered mean SFF of 165 Hz after half a years treatment with anabolic drugs for hormone dependent cancer. In four cases, the treatment could be followed for an entire year and the mean SFF was observed to drop down to 140 Hz on average which means nearly 1/2 octave. Contrary to our expectations, eight patients succeeded in increasing their mean SFF after logopedic treatment. However, in those six who returned for controls, 6 months after the completion of their voice therapy, the mean SFF had dropped again to almost the pre-treatment level.

9. Variations of the mean SFF in a loading test of the voice.

The GFA method was used in a field study on the places of occupation of eight patients (7 females, 1 male) with functional dysphonias before and after logopedic voice therapy. As expected from the earlier reported results, they showed no influence from voice therapy on their SFF when reading aloud in a silent environment. However, when talking spontaneously under occupational stress (in business, as teachers or administrators), the GFA measurements showed their mean SFF to have decreased by 7 % or more than a semitone after therapy.

A similar therapy-induced reaction was reproduced under laboratory conditions in an extended group of subjects. 33 females, aged 17 - 70 years (34 years on average), and 19 males, aged 17 - 63 years (40 years on average), were tested before and after logopedic voice therapy for functional dysphonia. In each test they had to compete with 70 dB white noise, reading aloud 30 minutes from a novel. SFF measurements were performed by GFA in silence immediately before and after the masking noise and three times during it. The results were expressed in percentage of change compared to the first reading immediately before the noise exposition started. They can be summarized in the following way (fig 3):

1. Competing with 70 dB white noise caused about a 10 % increase of the mean SFF both before and after voice therapy.
2. Before therapy there was an additional increase up to 15 % after reading aloud for 15 and 30 minutes. Such an additional increase did not take place after therapy.
3. Before therapy, the mean SFF was still increased by 5 % when the white noise had finished. In the same situation after therapy, there was an immediate recovery of the mean SFF to the original level.

As to SFF-range no statistically significant changes were observed after therapy.

The loading test described so far helps to indicate the condition of the voice or the disposition of the subject to react with inappropriate tenseness in stressing communicative situations. Further experience will show its suitability in the evaluation of functional voice disorders and of the effect of voice therapy.

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3. Pegoraro Krook, M.I., Speaking fundamental frequency characteristics of normal Swedish subjects obtained by glottal frequency analysis (GFA) 1986. Submitted for publication in Folia phoniat.

The extensive list of references to the thesis, comprising 295 titles, may be requested directly from the author.

Table 1a. Summary of previous research on the Speaking Fundamental Frequency (SFF) of adult males.
(from Pegoraro Krook, 1986)

Adult male subjects

Investigator	language	n	age	Pitch Fo(Hz)	Range*) (st)
Hollien & Jackson, 1973	Eng	157	18-26	129	6.4
Fitch & Holbrook, 1970	Eng	100	18-26	117	4.2
Majewski & al, 1972	Pol	103	ca 22 (univ stud)	138	7.2
Chevrie-Muller, 1971b	Fre	21	20-61	144	5.0
Hollien & Shipp, 1972	Eng	125	20-69	114	
Mysak, 1959	Eng	15	32-62	113	5.8
Kitzing, 1979	Swe	51	21-70	110	6.0
Horii, 1975a	Eng	65	26-79	113	9.6
Pronovost, 1942	Eng	6		132	
Rappaport, 1958	Germ	190		129	4.6
Canter, 1963	Eng	17		106	5.2
Neelley & al, 1968	Eng	14		100	3.7
Mikheev, 1971	Russian	6		128	9.6
Takefuta & al, 1971	Eng	24		127	7.8
Boë & al, 1975	Fre	30	adult	118	2.6
Atkins, 1976	Eng	5	adult	117	3.8
Arndt & Leithäuser, 1968	Germ		> 64	126	
Mysak, 1959	Eng	12	65-79	124	6.0
Hollien & Shipp, 1972	Eng	25	70-79	132	
"	Eng	25	80-89	146	
Mysak, 1959	Eng	12	80-92	141	6.6
Average SFF found in the literature		1003	18-92	124	5.8 (n=822)
Present study	Swe	198	20-79	113	5.3

*) double standard deviation measured in semitones (st)

Frequency (SFF) of adult females.

Adult female subject

Investigator	language	n	age	Pitch Fo(Hz)	Range[*)] (st)
Abberton, 1976	Eng	10	ca 20	242	9.6
Fitch & Holbrook, 1970	Eng	100	18-26	217	3.4
Dordain & al, 1967	Fre	22	ca 27	244	
Stoicheff, 1981	Eng	21	20-29a	224	
Linke, 1973	Eng	27	univ.stud.	200	4.8
Stoicheff, 1981	Eng	18	30-39a	213	
Saxman & Burk, 1967	Eng	9	30-40	196	4.9
Abberton, 1976	Eng	6	ca 40	180	7.6
Stoicheff, 1981	Eng	21	40-49a	221	
Saxman & Burk, 1967	Eng	9	40-50	189	5.5
Gilbert & Weismer, 1974	Eng	15	30-54a	163	4.7
Gilbert & Weismer, 1974	Eng	15	30-54b	164	6.5
Stoicheff, 1981	Eng	17	50-59a	199	
Chevrie-Muller & al, 1971a	Fre	95	18-99	223	7.2
" 1971b	Fre	21	19-72	226	4.6
Kitzing, 1979	Swe	141	21-70	193	5.4
Boë & al, 1975a	Fre	30	adult	207	3.4
Snidecor, 1951	Eng	6		212	6.1
Rappaport, 1958	Germ	108		238	4.2
Mikheev, 1971	Russian	5		255	9.1
Takefuta & al, 1971	Eng	24		186	11.2
Stoicheff, 1981	Eng	15	60-69a	200	
Arndt & Leithäuser, 1968	Germ		> 64	212	
McGlone & Hollien, 1963	Eng	10	ca 73	197	5.9
Honjo & Isshiki, 1980	Eng	20	75	177	
Dardain & al, 1967	Fre	22	76	209	
Stoicheff, 1981	Eng	19	70 & up	202	
McGlone & Hollien, 1963	Eng	10	86	200	5.4
Average SFF found in the literature		816	18-99	211	5.4 (n=641)
Present study	Swe	467	20-89	188	5.1

*) double standard deviation measured in semitones

a. nonsmokers b. smokers

Legends to the figures.

Fig. 1. Glottal frequency distribution by minicomputer (Nova 1220). The stars and exclamation marks show the percentage of occurrences in each class of semitones (from 59 Hz to 750 Hz) based on 1 700 measurements. The mean of this "raw" distribution is 175 Hz. After discarding measurements outside the main distribution (stars), when this has dropped under a certain level, the resulting "truncated" distribution (exclamation marks) shows a mean of 193 Hz. The pitch estimation for this voice by a group of trained listeners was 193.8 Hz.

Fig. 2. Simultaneous recording of optical glottogram (1.), electroglottogram (2.) and microphonesignal (3.) illustrating irregularity of vibrations and alternations of periods in vocal fry register. Female voice, 60 Hz or 120 Hz?

Fig. 3. Loading test of the voice, 33 female and 19 male subjects with functional dysphonia before and after therapy. - Percentage change of mean speaking fundamental frequency compared to initial reading aloud in silent surroundings.

A. Before voice therapy. B. After voice therapy.

1. Competing white noise for 1 minute.
2. Competing white noise for 15 minutes.
3. Competing white noise for 30 minutes.
4. Reading in silent surroundings immediately after the noise exposition.

Fig. 1

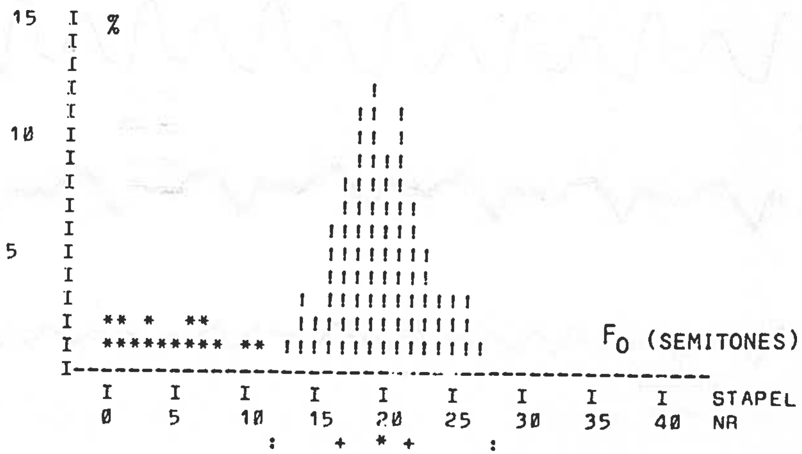

Fig. 2