Long-time average spectrograms of dysphonic

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Long-Time Average Spectrograms of Dysphonic Voices before and after Therapy

Key Words

Long-time average spectrograms · Functional dysphonia · Speaking voice · Voice quality after therapy

Abstract

Tape recordings before and after successful voice therapy from 174 subjects with non-organic voice disorders (functional dysphonia) were analysed by long-time averaged voice spectrograms (LTAS). In female as well as in male voices there was a statistically significant increase in level in the first formant region of the spectra. In the female voices there was also an increase in level in the region of the fundamental. The LTAS were compared to the results of a perceptual evaluation of the voice qualities by a small group of expert listeners. There was no significant change of the LTAS in voices with negligible amelioration after therapy. In the voices, where the change after therapy was perceptually rated to be considerable, the LTAS showed only an increase in intensity, but the general configuration of the spectral envelope remained unchanged. There was only a weakly positive correlation between the quality ratings and parameters of the spectra.

Gemittelte Langzeitspektrogramme (LTAS) von dysphonischen Stimmen vor und nach Therapie

LTAS-Analysen von 174 «funktionellen» Dysphonien wurden mit denen nach erfolgreich abgeschlossener Stimmtherapie verglichen. Die einzigen statistisch gesicherten Unterschiede waren ein Anstieg der Lautstärke im Bereich des 1. Formanten bei beiden Geschlechtern sowie auch ein Anstieg im Grundtonbereich bei den weiblichen Stimmen. Ausserdem wurde eine globale Bewertung der Stimmqualitätsveränderung vor und nach Therapie von einer Expertengruppe vorgenommen. Die nicht gebesserten Stimmen wiesen unveränderte LTAS-Befunde auf. Bei den deutlich gebesserten Stimmen wurde hingegen ein genereller Anstieg der Lautstärke festgestellt, nicht aber eine systematische Änderung der spektralen Hüllkurve. Die Korrelation zwischen bewerteter Stimmqualität und spektralen Parametern war indessen nur schwach positiv.

Le spectre moyenné de longue durée (LTAS) des voix dysphoniques avant et après la thérapie

Dans le présent travail des analyses LTAS de 174 patients avec dysphonies dysfonctionnelles avant thérapie sont comparées aux analyses après thérapie. Les seules différences vérifiées statistiquement étaient une augmentation du niveau de la région du premier formant chez les femmes ainsi que chez les hommes et du niveau autour du fondamental chez les femmes. La qualité globale des voix avant et après thérapie a été

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évaluée par un groupe de cinq thérapeutes, experts de la voix. Les analyses LTAS des voix jugées améliorées présentaient une différence significative des quatre paramètres utilisés pour décrire le spectre, correspondant à une augmentation générale de l'intensité, tandis que les spectres étaient presque inchangés pour les voix non améliorées. Pourtant, la corrélation entre les estimations de la qualité globale des voix et les paramètres spectraux est faible.

Introduction

From a clinical phoniatric aspect, long-time average spectrograms (LTAS) of continuous speech offer quite a number of advantages. Even if somewhat expensive, the necessary instrumentation is rather easy to obtain as there are several fast Fourier transform (FFT) analysers on the market prepared also to do the necessary averaging. The method can as well be implemented directly on available computers. As this is an acoustic analysis, the investigation is entirely non-invasive and it can be carried out even in the absence of the subject, provided his voice signal is accessible, e.g. on tape-recordings of sufficiently high quality. Contrary to several other analyses of vocal function, LTAS investigations are not restricted to isolated continuously sung tones. They permit an analysis of the ordinary speaking voice, which is important, as the majority of patients with vocal disturbances complain of problems with their speaking voice rather than when singing.

However, there are also a number of disadvantages and problems with LTAS. Even if it may be possible to neutralize the influence of isolated vowel articulation by averaging a sufficiently large number of spectra, there is always still a substantial influence from articulation and the resonators of the vocal tract on the spectrum. This may disguise important parts of the source signal from the larynx, e.g. – as will be discussed later – the level of the fundamental of the spectrum (called L_0) carries important information about the vibratory amplitude of the source signal, but it depends also on the characteristics of the sound radiation from the lip opening and on vocal tract filtering, both these mechanisms causing an increase in L_0 when the fundamental frequency is raised [1]. This may be one of the causes why the configuration of the spectrum is highly dependent on voice intensity and why there is a considerable variation of spectral characteristics between individuals, as has been emphasized by Hurme [2].

Last but not least, an LTAS presents an overwhelming abundance of data, hard to grip and hard to interpret. Therefore, the feasibility to use LTAS in routine clinical work with voice disorders will depend highly on methods to compress and reduce data without losing relevant information. As with most actual research on LTAS it is the aim of the present study to make a contribution to the development of such methods.

Earlier Research and Basic Theories

Many earlier investigations of the spectrum from pathological voices have focussed on dysphonia caused by organic disease of the larynx, like paresis or cancer, or on voice qualities signalling organic pathology, like roughness and breathiness [2–13]. Most of them found an increase in the level in the upper frequencies of the spectrum, usually in the range above 5 kHz, and gave the interpretation that this was due to turbulent noise components. However, there is a great overlap between spectra from normal and pathological voices. Wendler et al. [13], in spite of laborious statistical analyses of their data, had difficulties correlating ratings from perceptual evaluations of voice quality with spectral characteristics. However, their results could have been obscured by not using a device to eliminate the contributions of sibilant and other fricative articulation to the LTAS.

Our own interest in LTAS analysis starts from the idea that even small organic lesions of the larynx and their influence on voice function can most reliably be investigated by modern optical methods like microstroboscopy with video documentation [14]. As for the non-organic, so-called 'functional' voice disorders, however, by definition there are no lesions to be visualized and the clinician has to rely on subjective auditory evaluation of the voice quality. In these cases, the need for objective acoustic analysis of voice quality is most obvious. On the other hand, the discrimination between 'pathological' and 'normal' spectra can be expected to be more difficult, as the difference in voice quality usually is more subtle than in dysphonias due to organic lesions of the larynx.

One prerequisite for the correlation of long-time average (LTA) spectra to 'functional' dysphonias and for giving a physiological interpretation of the spectral findings is to know what characteristics of the spectrum to look for. Fortunately Fant has worked out a theory linking together physiological criteria of the laryngeal vibratory pattern and characteristics of the acoustic source spectrum.

According to this theory, recently summarized in a mathematical 'Four-Parameter Model of Glottal Flow' [15],

(1) the area of the glottogram, nearly correlating with the vibratory amplitude, corresponds to the level of the fundamental,

(2) the rate of the closing movement corresponds to the level of the overtones, a higher closing speed causing an increase in all higher partials, much the same as turning up the volume control of a stereo amplifier, and,

(3) the quality of the closing moment, i.e. the degree of briskness or sharpness in the event of closure, corresponds to the tilting of the spectrum, so a steep fall of the spectral envelope will depend on a soft closure and a more flat configuration on a brisk closure.

Intuitively, these spectral characteristics seem to be related to certain aspects of voice quality, like dullness, intensity, and sonority. The question is, if they can be used practically to characterize the LTAS of dysphonic voices. This has to some extent been shown already by the Stockholm research group. Based on analyses of singers' voices Sundberg and Gauffin [16] and Gauffin and Sundberg [1] showed that it was possible to interpret acoustical source spectrum data in terms of physiological glottogram data in accordance with Fant's theory, and they suggested to divide the spectrum into four frequency bands, representing the mean fundamental, the first formant region, the 2- to 5-kHz band, and the range above 5 kHz, respectively [17].

Based on a most thorough statistical factor analysis of results from perceptual evaluations of voice quality, Hammarberg et al. [18] were able to show significant correlations between spectral characteristics and the perceptual dimensions 'breathy–overtight' and 'hyper–hypofunctional', whereas no significant correlation was found between the dimension 'unstable–steady' and any acoustic variables.

In an earlier study of our own it was possible to show statistically significant differences between LTA spectra even from vocally healthy subjects, just changing their voice to a leaky or strained quality when reading aloud [19].

In the present article, we wanted to study if the sometimes rather subtle changes of voice quality due to therapy could be demonstrated in the LTA spectra.

Material and Methods

Subjects

The study is based on tape-recordings from 114 female subjects, aged 38 years on average (s = 12.5 years), and 60 males, 40 (10.0) years of age. The subjects were patients treated at our phoniatric department for non-organic voice disorders, most of them suffering from vocal fatigue (or phonasthenia) and/or functional hoarseness, generally of more than 1 year's duration. Most of them belonged to pedagogical or commercial professions, the great majority being non-smokers or having quit smoking as part of our therapeutic regimen. At diagnosis of the voice disorder, the quality of the voice was often described as either strained, creaky, asthenic or with elevated pitch level. The larynx, as examined by indirect laryngoscopy, usually through an operating microscope in combination with stroboscopy, was normal, apart from some slight insufficiency of glottal closure in some cases, mostly females. The patients underwent voice therapy and were freed from their complaints, which, however, not always implied an improvement of their voice quality. The number of therapy sessions was on an average 14 for the male subjects and 22 for the female subjects. The number of drop-outs, i.e. when a patient chose to finish therapy before reasonable success, was 4 males and 5 females.

Tape-Recordings

Recordings were made before and after therapy, the subjects reading an emotionally neutral text, 'The Northwind and the Sun' (in Swedish) at normal, comfortable intensity level in a sound-treated recording studio. The recordings were carried out according to our standardized and reproducible procedure with high quality equipment which is calibrated monthly: microphone: AKG CE 10, at 20 cm distance from the mouth, controlled by a head attachment; tape-recorder: Revox A 700, tape speed 7.5 inches/s.

Spectral Analysis

LTAS were obtained from a Brüel & Kjær Signal Analyzer 2033 by linear averaging with flat weighting over 128 triggered spectra. Pauses and unvoiced parts of the speech signal were eliminated by a gate controlled by a low-pass filter device. The frequency range of the spectra was 0–10 kHz with an original linear frequency resolution of 25 Hz, i.e. 400 equally distributed frequency classes.

Reduction of Frequency Data

The data from the original LTA spectra with linear division of the frequency axis were reduced by aid of a personal computer (ABC 80, Luxor, Sweden; software: Computer Aided Recording and Analysis of Human Voice, CARAHV, modified version, Patrik Lorentzon & Tobias Rydén, Department of Medical Engineering, Malmö General Hospital). The computer program transforms the original linear frequency scale of the spectrum into a scale which is logarithmically divided in the range above 500 Hz. Thereby, an enhanced resolution of the lower frequency range as well as a compression of the generally less interesting higher frequencies can be obtained in printouts of the spectra. The program can also compute the total effect (R) of the in signal within certain previously chosen frequencies (f_a, f_b) according to an algorithm

$$U^2 (f_a, f_b) = \int_{f_a}^{f_b} R(f)\, df,$$

where U^2 is a measure corresponding to the intensity level within that range. The result can be printed out by the computer. The frequency ranges chosen for this study were:

(1) the point of maximum intensity within the F_0 region ± 50 Hz, corresponding to the mean fundamental frequency, and hence called L_0;

(2) a range from the minimum level (L_{min}) between F_0 and the first formant peak of the spectrum plus 500 Hz, hence called L_1;

(3) the range between 2 and 5 kHz, called L_2;

(4) the range between 5 and 10 kHz, called L_5.

For computation of the statistics, the spectral levels were expressed as differences from L_1, the latter generally being the highest intensity level of the spectra. The differences of the results before and after therapy were labelled as DL_0, DL_1, DL_2, and DL_5, respectively. Furthermore, the program computed the ratio between the total intensity under 1 kHz and above 1 kHz, the result being called the inverted alpha quotient, the measure of alpha having been proposed by Frøkjær-Jensen and Prytz [5].

Quality Ratings

Five experienced voice therapists carried out a global quality rating of the voice recordings before and after therapy, considering only the degree of improvement according to their own personal standard and expressed in a scale of three steps: 0 = no change of voice quality, 1 = moderate improvement, 2 = considerable improvement.

For practical reasons, this part of the study could be accomplished for only 56 of the male voices and 72 of the female voices, the average rating scores (and standard deviations) being 1.03 (0.50) for the males and 1.2 (0.56) for the females. The spectral measurements from voices with minimal and considerable improvement (average rating of 0–0.6 and 1.8–2.0, respectively) were compared statistically. Furthermore, the correlations between the averaged ratings of voice improvement and the changes of spectral measurements were computed.

Results

The results from all 174 subjects before and after therapy appear in table 1. They can be characterized as a general increase in the intensity levels within the chosen frequency ranges, except a minimal decrease in the 2- to 5-kHz range for the male voices. The increase was statistically significant only for the range corresponding to the first formant in both sexes and for the level of the fundamental for the female voices. Remembering that as a method of standardizing all the levels but the first formant level were expressed as differences from that level, the result means that there was a general increase in the levels of the spectra, but no statistically significant change of their configuration. This compares with the result that there was no significant change of 1/alpha after therapy.

These results could to some extent depend on the voice therapy having too diverse effects on quality. Therefore we compared groups of voice samples with unanimously high and low scores in the ratings, respectively. The results, as shown in table 2, were in close agreement with those from the entire study. Whereas the spectra from the unchanged voices actually were very similar to those before therapy, spectra from the improved voices showed a general increase in level in all the selected frequency ranges. For the female voices, this increase was statistically significant in the F_0 and F_1 ranges (fig. 1).

Table 1. LTAS levels (dB) of all subjects (means and standard deviations)

	Females (n = 114)	Males (n = 60)
L_1 before therapy	88.34 (3.24)	93.15 (4.32)
L_1 after therapy	90.56 (3.61)	95.09 (3.64)
Difference L_1	−2.22***,[a]	−1.94***
L_1–L_0 before therapy	2.19 (2.31)	3.72 (2.34)
L_1–L_0 after therapy	2.96 (2.46)	4.18 (2.58)
Difference L_0	−0.77***	−0.46
L_1–L_2 before therapy	14.87 (2.27)	14.73 (2.64)
L_1–L_2 after therapy	15.27 (2.76)	14.47 (2.29)
L_1–L_5 before therapy	10.77 (4.37)	15.86 (4.76)
L_1–L_5 after therapy	11.12 (3.99)	16.21 (4.78)
1/alpha[b] before therapy	1.123 (0.036)	1.132 (0.031)
1/alpha after therapy	1.117 (0.03)	1.125 (0.028)

Therapy-dependent differences for L_2, L_5 and 1/alpha statistically not significant and not shown.

[a] Statistics by t test on paired observations.

[b] Ratio < 1 kHz/> 1 kHz levels.

For reasons of orientation, we calculated the Pearson product moment correlation (r_{xy}) between the therapy-dependent changes in intensity levels and the rating scores, even if these are not parametric. The only statistically significant correlation (r = 0.36) was in the range of the first formant of the female voices.

Discussion

The most prominent result of this study seems to be that voice therapy causes a general increase in the LTAS level with a slight dominance of the region of the first formant, and that this applies especially for voices

Table 2. Groups of unchanged voice quality (rating scores 0–0.6) compared to groups of much improved quality (scores 1.8–2.0)

	Females		Males	
	unchanged (n = 18)	improved (n = 18)	unchanged (n = 15)	improved (n = 10)
L_1 before therapy	89.6 (4.1)	87.7 (2.7)	92.7 (4.9)	93.2 (4.1)
after therapy	89.8 (4.6)	91.4 (3.7)	93.5 (3.0)	95.9 (2.8)
DL_1	-0.2	-3.7***	-0.8	-2.7^{NS}
L_1–L_0 before therapy	2.00 (2.30)	1.54 (1.93)	3.4 (3.4)	3.3 (2.3)
after therapy	1.76 (2.73)	3.23 (2.28)	3.6 (2.3)	4.5 (2.3)
DL_0	0.24	-1.69*	-0.2	-1.2^{NS}
L_1–L_2 before therapy	14.43 (2.29)	14.11 (1.60)	14.0 (1.8)	14.8 (3.4)
after therapy	14.71 (3.05)	14.96 (2.36)	14.3 (2.5)	15.0 (1.8)
DL_2	-0.27	-0.85^{NS}	-0.3	-0.2
L_1–L_5 before therapy	11.57 (4.26)	9.58 (4.45)	15.1 (5.0)	15.5 (7.4)
after therapy	11.44 (4.96)	10.77 (4.60)	16.7 (5.0)	16.5 (6.5)
DL_5	0.13	-0.19^{NS}	-1.6	-1.0

No difference of 1/alpha was observed between groups or depending on therapy.
Figures express average level in decibels and standard deviation.
Statistics of therapy-dependent differences by t test on paired observations.

rated as well improved. Knowing that the general SPL of a spectrum is dominated by the level of the first formant, this result is in agreement with our own earlier SPL measurements of voices before and after therapy, showing an increase of L_{eq} of about 2 dB [20]. So, one is reminded of a comment by Hurme [2]: Should some of the properties of a good voice be reinterpreted as properties of a loud voice?

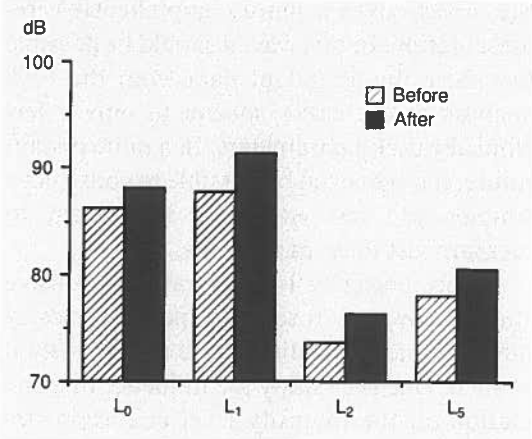
However, the result may also to some extent depend on a neutralizing effect on individual spectrum characteristics caused by the averaging of the measurements from many voices. This may be illustrated by the demonstration of some *individual* cases from our material:

(1) a male voice (7611 J.P.) with a general increase in the level of all four frequency ranges (fig. 2a) showing a generally improved projection;

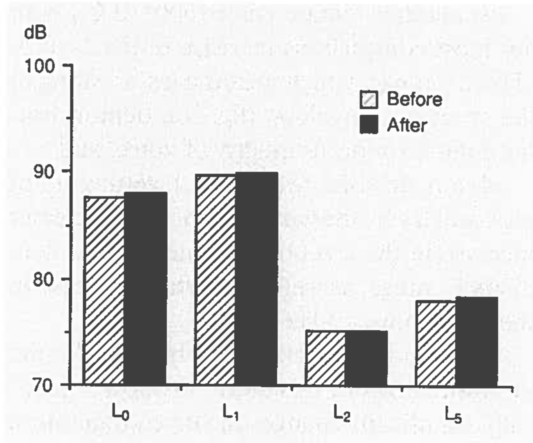
(2) a female voice (7496 C.E.) with an increase in all frequencies but the fundamental (fig. 2b) and a less asthenic voice;

Fig. 1. Summarized intensity levels in chosen frequency ranges before and after voice therapy. **a** Female voices, improved. (Frequency ranges as defined in the text.) **b** Female voices, unchanged.

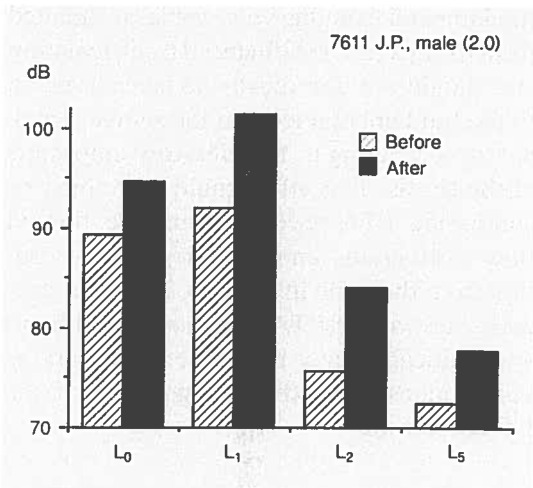
Fig. 2. a LTAS characteristics of male voice showing generally improved projection: increase in the level of all four frequency ranges. **b** Female voice, less asthenic after therapy: increase in all frequency ranges but the fundamental. **c** Female voice, more sonorous after therapy: increase especially in L_2, meaning a lesser tilting of the spectrum envelope.
d Male voice, with less vocal fry after therapy: increase especially in L_1.



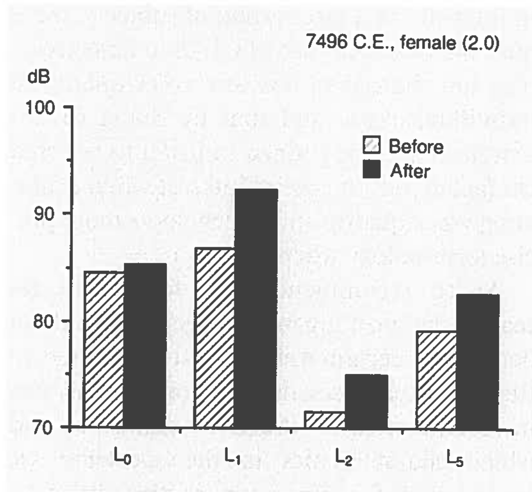
1a



1b



2a



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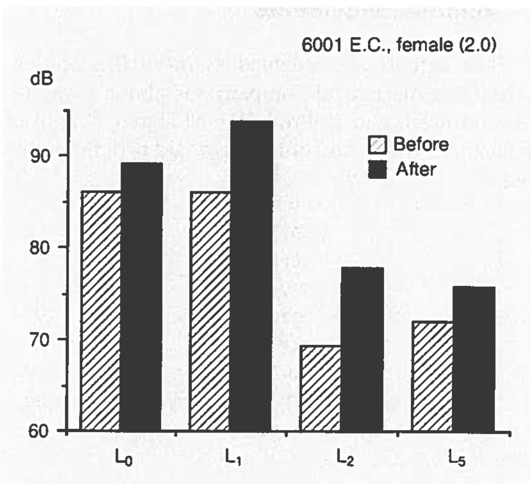
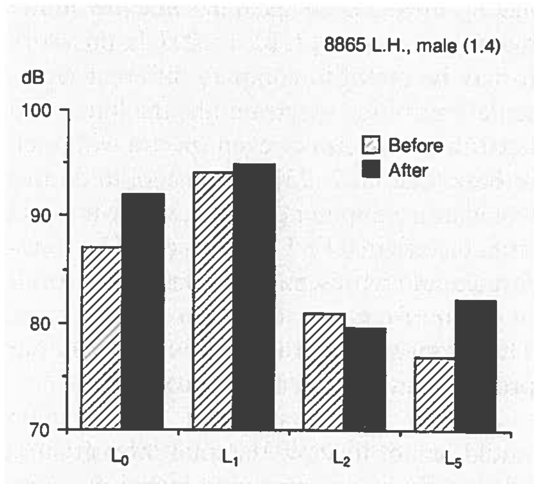


2c



2d

(3) another female voice (6001 E.C.) with her most conspicuous increase in the 2- to 5-kHz (L_2) range, which means a lesser tilting of the spectrum envelope (fig. 2c), demonstrating a more sonorous quality of voice, and

(4) a male voice (8865 L.H.), getting rid of his vocal fry by therapy, and showing a greater increase in the level of his fundamental than of his F_1 range, as well as a certain increase in the level above 5 kHz (fig. 2d).

The conclusion may then be that despite the difficulties in this study to show statistically significant changes in the configuration of the LTA spectra but only a general increase in intensity in a large group of subjects, there may still be a great use of LTAS to objectively measure changes of acoustic voice quality in individual cases, and that by doing so, researchers may be trained to listen to selected characteristics of special interest when evaluating voice quality and to develop a more precise terminology when doing so.

As to recommendations for future research, the most urgent task seems to study in depth, how certain well-defined parameters in the perceptual assessment of voice quality can be documented in the LTA spectrum, and which characteristics in the spectrum we should look for, first steps in this direction having already been taken in some previously mentioned studies [7, 12, 15, 21]. In this work it may be useful to compare different representations of the spectrum like the linear and logarithmic spectra or even spectra with mel- or bark scales [22, 23]. A nice tool to do this would be a computer program, where the data from the original FFT analysis could be transformed into representations of intensity levels of certain frequency ranges in the spectrum. These ranges should not be fixed like in our program but possible to be chosen freely.

Another improvement of our program would be not to show the total intensity of a selected frequency range but rather the average, which gives a more comprehensible representation. In this way, it should be possible to reduce the abundant data from the FFT analysis of the entire spectra to only a few clinically useful parameters. In a more distant future, it might even be possible to construct a simpler and less expensive instrument to measure just these parameters.

Before engaging in such rather extensive studies, however, it seems important to carry out some critical testing of the LTAS method as such. One is to study the influence of articulation on the intensity level of certain frequency ranges. For instance, the level of the fundamental from the voice signal as radiated from the lips can be influenced by articulation and should not uncritically be taken as equal to the fundamental level in the source signal, nearly correlating to the vibratory amplitude of the glottis. This effect could be studied by comparing LTA spectra of inverse filtered flow glottograms and ordinary tape-recordings from the same utterances. The other necessary test of the LTAS method would be to systematically study the influence of varying voice intensity on the configuration of the LTA spectrum.

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