 特別講演

Voice Range Profile Measurements of Speaking, Shouting, and Singing Voices

Historical Development and Clinical Use

Hacki, T., Loebell E.

Summary : This paper reviews the development of different kinds of voice range profile measurements from the past to the present stage.

The combined measurements of the speaking, shouting, and singing voice range profiles are presented and the method explained which was developed in Hannover.

After analysis of more than 300 persons with normal voices and over 700 patients with voice disorders the relationship between the three voice profiles have been evaluated and described. The voice range profiles may be documented and superimposed for comparison before and after therapy.

In functional voice disorders there is often some discrepancy between the singing, shouting, and speaking voice profiles.

Despite a normal singing voice profile, the speaking voice area is restricted and displaced.

In organic voice disorders the singing voice profile is found more or less reduced particularly in the head register, or all modalities of the voice production are effected.

Voice range profile measurements have been proved useful in clinical practice. The method should become more attention for its use in diagnostics and for therapy monitoring in all kinds of voice disorders, especially for expert opinion.

I.

Physically speaking, the voice function represents the conversion of aerodynamic energy into acoustical energy. The acoustical results exhibits three parameters that are relevant from the clinical point of view : voice pitch (frequency), voice intensity (sound pressure level), and tone (frequency spectrum).

By measuring the gamut one examines the ability of the vocal mechanism to produce low as well as

high voices. This parameter of the voice has been extensively covered even in older literature. The range of the voice can easily be determined by means of an auditive pitch comparison with a musical instrument.

The phonation mechanism is also capable of producing soft as well as loud voices. The voice dynamics or, to put it another way, the range of dynamics, however, cannot be precisely evaluated by auditive means.

Simultaneous registering of two voice parame-

ters, voice pitch and voice intensity, allows a two-dimensional presentation of the voice production.

Measuring the frequency-dependent range of dynamics of the voice in the German speaking countries is referred to as "Stimmfeldmessung" (voice range profile measurement) (Rauhut and coll., 1979) whereby the frequency-associated minimum and maximum phonation sound pressure levels are determined and made visible. It is not so much the area enclosed by the boundary lines that is of concern here but, rather, the boundary lines themselves and their path. The anglo-american term "voice range profile" is more descriptive of this approach.

The boundary lines of the voice range profile represent the respective actual production limits of the voice mechanism with respect to pitch and volume. These production limits indirectly provide information regarding for instance, muscular tension relations as well as CNS control of the voice mechanism. Voice range profile measurement can be compared to other function tests generally used in medicine, such as : hearing range profile in audiometry, visibility range profile and visual determination in ophthalmology. In the Netherlands, Belgium and in northern Europe it is referred as "Phonetogram", too. It should be mentioned that we regard the term "singing voice range profile" to be more accurate than "voice range profile" because with the recording of a voice range profile it is always the singing voice which is tested (Hacki, 1988).

Frequency-related sound pressure level measurements have been carried out by Wolf and coll. as early as 1935. There are reports of simultaneous measuring of voice pitch and intensity by Clavet and Malhiac dating back to 1952.

The diagnostic value of "voice curves" has been affirmed by Luchsinger (1953).

Vogelsänger (1954) generated "sound intensity curves" for the presentation of singers' performances. Waar and Damste (1968) recorded the "phonetogram" which has been recommended by Damste (1970) for use in phoniatic practice, for instance, for the evaluation of singers' performance, voice development, the pathological voice, as well as the success of therapy.

Schutte (1975, 1980) views the phonetography as a method for examining the voice well suited for clinical practice. He described its advantages in diagnostics and qualification assessment examinations for voice-related professions.

Coleman and colleagues (1977) measured not only the physiological but also the musical voice range or, respectively, the dynamics range and generated "fundamental frequency-sound pressure level profiles" (FO-SPL) .

Dejonckere (1977), Rauhut and colleagues (1979), Gross (1980), and Thürmer (1984) also point out the clinical value of voice range profile measurement. Using "phonograms", Komiyama and colleagues (1984) examined the development of voice intensity and voice pitch dependent upon age.

The classical voice range profile examination by means of a piano and phonometer is subject to continuous technical development.

Rauhut and colleagues (1979), and Gross (1980), presented a semi-automatic method with which the values measured for the sound pressure level — which were by the examiner regarded as maximum and as minimum — are stored by the apparatus or, respectively, entered in a voice range profile form upon actuation of a key. A microprocessor-controlled apparatus designed for clinical practice was developed by Pedersen and Hansen in 1984. This device automatically measures sound pressure level and frequency whereby the numerical values appear on a display. The tone is to be repeated singing by the patient ; then, one can see on the display whether the repeated tone was too flat or too sharp. If the correct tone is hit then the sound pressure is measured and stored together with the frequency value.

Sonninen and colleagues (1985) generated "computer voice fields" of continuous speech. Vilkman and others (1986) reported on comparative studies between the voice generation of an extirpated larynx blown-on with air and the physiological phonation by means of a computer voice range profile.

The evaluation of the voice range profile diagrams is performed visually. Hereby, the course of the "piano curve" as well as of the "forte curve",

voice range and voice dynamics, indentations etc. are evaluated. The area contents of the voice range profile may be evaluated as well.

In the "normal care" the curves run without any material indentations, the outer-most frequency boundaries represent a voice range of about 2.5 octaves, the outer-most dynamical boundaries represent voice dynamics of about 50 dB (Schultz-Coulon, 1988).

Based on the examination of short-term variability and long-term variability of the voice range profile states as well as of the subjective influence of the respective examiner, Gramming (1988) was able to prove the consistency of the voice range profile measurement and expressed the opinion that the phonetogram provided a reliable description of some aspects of voice production.

Dickopf (1985) as well as Flach and colleagues (1988) worked on variance analytical studies with respect to the voice range profile. Hereby, the use of a multi variance analytical method of voice range profile measuring values enables an improved assessment of the voice range profile configuration as well as the area contents. Lowest dynamics, lowest piano intensity, medium piano intensity, forte intensity, area contents, piano curve index, and forte curve index are computed for three or four classes of examined persons (singers or voice students, laymen and persons with voice diseases) and compared to each other. The authors view the advantages of this method to be the inter-individual assessments and the separation of the above-named classes.

Dickopf and colleagues emphasized that the isolated consideration of a voice range profile involves the danger of misinterpretation as only two parameters out of the multi-factor events of phonation are evaluated. For an improved assessment of the voice range profile state combined methods are used.

Combined Methods Based on Voice Range Profile Measurement.

As early as 1970, Damste suggested to document, simultaneously with phonetography, tone characteristics of the voice using a consistent nomenclature.

Heinemann and colleagues (1982) pointed out that often the voice range profile measurement alone will be insufficient to differentiate trained from

untrained and physiological from impaired voices. While acknowledging the great diagnostic value of voice range profile measurements, the authors proposed to complement this by including the voice tone into the graphic presentation of the voice range profile.

Stürzenbecher und others (1982) described a developed apparatus for voice range profile measurement which records the high singers' formant. As the apparatus provides no frequency measuring, the notes played are to be repeated singing by the person tested.

Seidner and colleagues (1981) performed a numerical evaluation of the "spectral voice range profiles". Hereby, besides the voice range profile data (frequency and sound pressure level), the singers' formant is taken into evaluation. Three classes, professional singers, voice students, and non-singers with no voice diseases, can be differentiated using this method.

Komiyama and coll. (1982) complemented voice range profile measuring by means of determining the airflow-rate measured by way of pneumotachography.

Gramming, Gauffin and Sundberg (1986) recommended to record the amplitude of the first partial note and to enter them into the phonetogram. The dynamical limits of the voice range profile, i. e. the respective actual sound pressure level values, can be generated by differing ways of phonation. This provides information as to whether the respective note was sung by means of whispered phonation or using strained phonation.

Seidner (1985) determined that the assessment of the speaking voice by means of the singing voice range profile, in spite of the fixed relation between the two, cannot be considered optimum. In order to attain an improved assessment, he generated "speaking voice profiles". The persons to be tested were asked to count, soft at first and then with increasing loudness. The frequency of the speaking voice was selected at the keyboard of the voice range profile measuring apparatus in accordance with the audition of the examiner, and the associated sound level was read off. The sound level values so obtained were drawn into the voice range profile

as speaking voice profiles. By employing this method the author was able, for instance, to evaluate better the increase potential of the voice. Using the same procedure, Seidner and others (1988) determined that test persons, which are trained in singing, reach sound levels almost equal to those attained with maximum loud singing at the respective frequency. Non-singers with no voice diseases exhibited marked level differences between shouting and loud singing in favor of the shouting intensity. Persons without voice diseases shout with an intensity of more than 90 dB, according to his findings. This value should be taken into consideration in qualification assessment examinations.

Gramming (1988) examined the speaking voice during reading of a text at different levels of loudness. The basic frequency as well as the temporal average of the sound pressure level (Leq) of the voice are subsequently analysed and drawn into the voice range profile as trajectories. Based on the results of the examination of 18 tested persons and 20 patients the author esteems it desirable to analyse the speaking voice of the voice impaired, patients in relation to their voice range profiles : rather than speaking of an optimum voice frequency she regards it as more appropriate to speak of optimum trajectories with respect to the voice range profile.

II.

Method and clinical use

The voice range profile measurement applies to the functional capacity of the voice mechanism with respect to voice range and voice dynamics.

The boundaries of the voice range profile represent the respective actual limits of voice performance with respect to pitch and intensity. These limits of performance indirectly provide information concerning muscular tension capability as well as psychomotor control of the voice organ.

From the classical viewpoint voice range profile measurement is concerning with the examination of sustained vowels — or sung — notes ; it is for this reason that we regard the term "singing voice range profile" adequate.

The classical voice range profile measurement is

carried out by means of a piano and a sound pressure level meter. The note generated by the instrument is to be repeated by the patient in singing form, soft as well as loud. The minimum and maximum sound pressure level values of the correctly sung note are manually entered into the voice range profile form. The frequency matching of the note played and the note repeated singing should be checked by the examiner. Amusical patients or, perhaps, amusical examiners render the test more difficult (it is a known fact that many patients with voice disorders are amusical). This limits this method.

By means of the classical voice range profile examination it is possible to determine the voice pitch and intensity of maintained notes, in other words, only the singing voice performance can be assessed.

Based on the experience that with respect to the ratio of singing voice and speaking voice there are clinically relevant relations as well as frequently appearing discrepancies, we regard the assessment of the speaking voice performance as equally important.

This is possible by using the combined speaking voice range profile/singing voice range profile examination : In a manner similar to the singing voice range profile measurement, we assess range and dynamics of the speaking voice and call the result "speaking voice range profile".

The recording and visualizing of singing, shouting, and speaking voice performance is carried out using an automatic voice range profile measuring apparatus from the company Homoth Hamburg, W. Germany (Circuit Diagram, Fig. 1). This device was developed at the Department of Phoniatics, Hannover Medical School, by Hacki and Loebell.

In comparison with the classical method the fully automatic voice range profile measuring system exhibits the following advantages :

1. automatic frequency determination
2. automatic sound pressure level determination
3. immediate graphic presentation of the measured data on a display, to guarantee
 - a) visual supervision of the voice production by the examiner and

Fig 1

- b) visual self-supervision of the voice production by the patient
4. storage of measured data
5. print-out of the measurement results
6. comparison of the findings by means of direct projective superimposing, (in order to — among other things — visualize the course of therapy or to compare speaking voice range profile with singing voice range profile).

In cases where both, the patient as well as the examiner, are not sufficiently musical — which is something that happens often with patients having voice disorders — it is a requirement that automatic frequency determination is provided, because in these cases the patient is unable to repeat the notes played to him or, respectively, the examiner is unable to precisely evaluate the frequency ratio between the note played and the note repeated. Such automatic frequency determination is important for recording the continuous speaking. Automatic identification of frequency and sound pressure level allows determination of the habitual frequency of the speaking voice and the habitual phonation intensity in that the frequency of occurrence of the values measured for frequency and sound pressure level are being presented in the form of bar charts while the speaking continues.

Similar to the singing voice range profile the result is a two-dimensional representation of the entire voice range and the entire dynamics of the speaking or, of the shouting voice, that is the speaking voice range profile of the shouting voice range profile respectively. The Y-axis represents the phonation intensity measured in dB (linear), the X-axis shows the voice frequency represented by the piano keyboard. Uninterrupted line = singing voice

range, dotted line = speaking and shouting voice range profile.

Procedure of the Combined Speaking, Shouting and Singing Voice Range Profile Examination

It has been established as useful to start off with examination of the speaking voice. At the beginning of the examination it is easier for the patient to speak than to sing.

Firstly, the patients read out a text, as relaxed as possible with habitual loudness. The measuring points become visible on the monitor within the system of coordinates for the voice range profile.

The frequency of occurrence of these measuring values is presented in the form of bar charts by means of which one can determine the habitual frequency of the speaking voice as well as the habitual phonation intensity.

Following this, the examination is continued while the prior obtained measuring values are kept.

The patients are asked to count. They are instructed to start phonating in a relaxed manner, soft, followed by habitual intensity, then lecturing intensity and then louder still. Subsequently, the patients are asked to shout a sample sentence "Hallo, Anton come here" for four or five times. The instructions always relate exclusively to the phonation intensity, never to the pitch of the speaking voice.

After the shouting, when a sufficient number of measuring points for evaluation are available on the monitor, the measuring data of the speaking voice examination are stored.

During the recording of the singing voice range profile the patient sings soft tones, starting from the individually habitual speaking voice frequency, first up towards higher frequencies then down towards lower ranges. Following that forte tones, sometimes

Fig 2

in the form of crescendi, are phonated in high and thereafter in low voice ranges. During the recording of the singing voice range profile the patients are asked to self-supervise themselves by using the monitor ; this enables them — as well as the examiner — to recognize areas of the voice range profile lacking measuring points. Then, the missing voice areas are supplemented — if possible — with notes played by a sound generator to the patients.

The opportunity of watching their voice performance visually on the screen serves to motivate patients in their voice production. Amusical patients who cannot repeat the notes as played to them are asked to phonate low, high, soft, and loud. Several

repetitions of this phonation process allow the recording of a sufficient number of measuring data to determine a "screening voice range profile".

Upon actuation of a key by the examiner the measuring points at the boundaries are connected with each other so as thereby surround the voice range profile. Thereafter, singing voice range and speaking voice range are presented on the monitor superimposed upon each other and printed in table form together with their numerical reference values (Fig. 2).

Now, it is possible to directly compare the singing voice production with the speaking voice production and to analyse the inter-relationship of the both.

We have analysed speaking voice and singing

Fig 3

voice performances of more than 300 persons with no voice disorders and over 700 patients with voice diseases.

For the persons with no voice problems the results can first be summarized as follows :

a) Under normal circumstances the speaking voice range profile lies within the lower third of the frequency range of the singing voice range profile.

b) The dynamics limits of the speaking voice range profile approach closely or reach entirely the dynamics limits of the singing voice range profile.

c) The shouting voice is represented by a specific voice range profile. This lies in the register transition area between chest register and head register and may extend beyond the upper dynamics limit of the singing voice range profile.

Thus, in the optimum case the person tested can exploit his entire voice dynamics in the respective frequency range also for the speaking voice production : He is able, by way of speaking as well as singing, to phonate equally soft as well as loud, his speaking voice neither lies too high nor too low in relation to his singing voice.

He is capable of shouting equally loud or even louder than he can sing. His shouting voice represents the highest frequency as well as the loudest range of his chest register. Fig. 2 represents a normal voice, female singer, age 32, soprano.

Optimal relationship between speaking, shouting and singing voice range profiles.

a) the speaking voice range profile (sp) lies within the lower third of the frequency range of the singing voice range profile,

b) the dynamics limits of the speaking voice

range profile (sp) reach (entirely) the dynamics limits of the singing voice range profile,

c) the shouting voice range profile (sh) approaches high upper dynamic limit (forte-contour) of singing voice range profile. Shouting voice range profile lies in the register transition area between the chest and the head register. Fig. 3 demonstrates the findings of a 18-years old woman : With persons with untrained voices but no voice disorders we find equal results, as is the case with this young woman : The speaking voice range profile is situated as normal, within the singing voice range profile, the shouting voice range profile, however, lies above the singing voice limit within the indentation of the singing voice range profile. The woman is capable of shouting with normal strength ; however, her singing voice is weak in the register transition area. The location of the shouting voice indicates dynamical reserves which enable the singing voice to be trained in this frequency range. This reserve may be activated and used by training or voice treatment.

With patients having voice disorders we were able to observe differing relations between singing voice and speaking voice performance as well as discrepancies. We will demonstrate some clinical examples :

Fig. 4 represents the mutation voice disorder of a 16-years old boy : The dynamics of the singing voice range profile in the middle range is severely restricted ; the position of shouting voice range profile shows approximately where upper dynamics limit (forte contour) of singing voice range profile should be.

In cases of functional voice disorders we frequent-

Fig 4

Fig 5

ly find a restricted, displaced speaking voice range profile while the singing voice range profile is normal or acceptable.

Fig. 5 shows the singing voice and speaking voice range profile of a female teacher (age 28). She exhibits a good singing voice performance ; however, she has a peculiar speaking voice which is not sufficiently capable of increasing and becomes strikingly high-pitched with rising intensity. Consequently, the speaking voice range profile is restricted in its dynamics and shifted in the direction of higher frequencies showing a tendency towards functional dysphonia. This person is subject to permanent stress on her voice which is the reason why she developed a voice disorder, a so-called dysphonia on exertion, the pathogenic mechanism of which was objectivized with the aid of this method. For the first time now our method proves objectively this condition of voice disorder which seems relevant also for expert opinion.

Fig. 6 represents a good singing voice performance but a pathological speaking voice perfor-

mance. The patient has what is called hyperfunctional dysphonia whereby the voice organ shows excessive muscular tension.

The speaking voice sounds deep, strained, and monotonous. The speaking voice range profile extends beyond the lower frequency boundary of the singing voice range profile. The speaking voice range profile appears to be shifted in its entirety towards the direction of lower frequencies.

Using these findings it was possible to determine one of the aims of therapy : The speaking voice was to be brought from its too-low position into a higher voice range, and/or the lower frequency boundary of the singing voice range profile was to be shifted down towards lower frequencies by means of relaxation exercises. This goal was attained by means of voice therapy.

In cases of organic voice disorders singing and speaking voice range profiles often exhibit a behavior different from functional dysphonias. Here, it is more likely the higher range of the singing voice that tends to be affected by the restriction or singing

Fig 6

Fig 7

voice and speaking voice are equally affected.

In cases of nodules of the vocal folds we find a typical state (Fig. 7). We see here the voice range profiles of a 19-years old female patient : Neither singing voice in the chest register nor speaking voice are quantitatively restricted. Even the shouting voice is represented. However, the singing voice in the voice register is totally non-existent. During singing in the head voice register — i. e. in the range of high notes — the borders or, respectively,

the edges of the borders of the vocal folds play an important part. Phonation is materially impaired by organical alternations of these areas. The findings disappear after treatment.

Reinke's edema, woman, age 46. Very deep, male voice range, only the frequency range of the shouting voice, which is present only in fragments, indicates the fact that it is a female voice.

Same female patient after surgery, so called "stripping" of the vocal folds (Fig. 9).

Fig 8

Fig 9

Conclusion

Nobody would doubt the necessity of an audiogram in the diagnostics of hearing disorders. Voice range profile measurement should become more attention for use in diagnostics and therapy of voice disorders.

The purpose of the combined singing voice and speaking voice range profile examination is to compare both voice performances by means of direct projective superimposing. These findings are helpful for

1. every-day voice diagnostics, also useful for expert opinion
2. determination of therapeutical approaches
3. determination of aims for therapy
4. objective evaluation of therapy results, and
5. they are necessary for the phoniatic assessment in connection with voice — and speech — related professions.

References

- 1) Calvet, J., Malhiac, G. : Courbes vocales et mue de la voix. J. fr. Oto-Rhino-Lar., 1 : 115~124, 1952.
- 2) Coleman, R. F., Mobis, J. H., Hinson, J. K. : Fundamental frequency sound pressure level profiles of adult male and female voices. J. Speech Hearing Res., 20 : 197~204, 1977.
- 3) Damste, PH. : The fonetogram. Practico oto-rhino-lar., 32 : 185~187, 1970.
- 4) Dejonckere, Ph. : Le phonetogramme, son intérêt clinique. Cahier d'oto-rhino-laryngol., 12 : 865~872, 1977.
- 5) Dickopf, G. : Untersuchungen zur Stimmfeldmessung im klinischen und gesangspädagogischen Einsatz. Diss. A, Dresden, 1985.
- 6) Dickopf, G., Flach, M., Koch, R., Kroemer, B. : Varianzanalytische Untersuchungen zur Stimmfeldmessung. Folia Phoniatic., 40 : 43~48, 1988.
- 7) Gramming, p., Gauffin, J., Sundberg, J. : An attempt to improve the clinical usefulness of

- phonetograms. *J. Phon.*, 14 : 421~427, 1986.
- 8) Gramming, P. : The Phonetogram. Lindbergs Blankett AB, 1988.
 - 9) Gross, M. : Stimmfeldmessung, eine objektivere Methode der Stimmdiagnostik. *Sprache-Stimme-Gehör*, 4 : 100~101, 1980.
 - 10) Hacki, T., Loebell E. : Neue Aspekte der Stimmfeldmessung. Das Sprechfeld im Stimmfeld. *Liber Amicorum Damsté*, Utrecht, 1987.
 - 11) Hacki, T., Loebell E. : Phonetography of singing voice and speaking voice in professional singers. *Acta Phoniat. Latina*, X (3) : 342~344, 1988.
 - 12) Hacki, T. : Die Beurteilung der quantitativen Sprechstimmleistungen. Das Sprechstimmfeld im Singstimmfeld. *Folia Phoniat.*, 40 : 190~196, 1988.
 - 13) Heinemann, M., Gabriel, H. : Möglichkeiten und Grenzen der Stimmfeldmessung — Vorstellung des Heiserkeitsfeldes als Ergänzung der Methode. *Sprache-Stimme — Gehör*, 6 : 37~42, 1982
 - 14) Komiyama, S., Watanabe, H., Ryu, S., Kannae, S. : Phonogram. A New Phonometer. *Otologia (Fukuoka)*, 28 : 412~415, 1982.
 - 15) Komiyama, S., Watanabe, H., Ryu, S. : Phonetographic relationship between pitch and intensity of the human voice. *Folia Phoniat.* 36 : 1~7, 1984.
 - 16) Luchsinger, R. : Schalldruck- und Geschwindigkeitsregistrierung der Atemluft beim Singen. *Folia Phoniat.*, 3 : 25~51, 1951.
 - 17) Pedersen, M. F., Linskov Hansen, T., Linskov Hansen, H., Munk, E. : A Phonetograph for use in Clinical Praxis. *Acta Otolaryngol., Suppl.*, 412 : 138 (Stockh.), 1984.
 - 18) Rauhut, A., Stürzenbecher, E., Wagner, H., Seidner, W. : Messung des Stimmfeldes. *Folia Phoniat.*, 31 : 119~124, 1979.
 - 19) Seidner, W., Wendler, J., Wagner, H., Rauhut, A. : Spektrales Stimmfeld. *HNO-Praxis*, 6 : 187~191, 1981.
 - 20) Seidner, W. : Objektive Qualitätsbeurteilung der Stimme mittels Dynamikmessungen. *Z. Klin. Med.* 40, Heft 20, 1985.
 - 21) Seidner, W., Wardius, T., Zimmermann, E. : Dynamikmessungen der Sprech- und Singstimme aus Klinischer Sicht. *Proc. XVth Congr. UEP Erlangen* 14.~18. 9. 1988.
 - 22) Sonninen, A., Hurme, P., Toivonen, R., Vilkman, E. : Computer voice fields of connected speech. *Papers in Speech Research*, 6 : 93~111, 1985. Jyväskylä.
 - 23) Schultz-Coulon, H. J., Asche, S. : Das "Normstimmfeld"—ein Vorschlag. *Sprache-Stimme-Gehör*, 12 : 5~8, 1988.
 - 24) Schutte, H. K. : Over het Fonetogram. *Logopedie en Foniatrie*, 47 : 82~92, 1975.
 - 25) Schutte, H. K. : Untersuchung von Stimmqualitäten durch Phonetographie. *HNO-Praxis*, 5 : 132~139, 1980.
 - 26) Stürzenbecher, E., Wagner, H., Becker, R., Rauhut, A., Seidner, W. : Einrichtung zur simultanen Registrierung von Stimmfeld und hohen Sängerformant. *HNO-Praxis*, 7 : 223~226, 1982.
 - 27) Thürmer, St. : Das Phonetogramm in der Praxis. In : Stottern und Stimme. G. Kattenbeck, L. Springer (Hrsg.), 165, 1984.
 - 28) Vilkman, E. : Sonninen, A. ; Hurme, P. ; Observation on voice production by means of computer voice fields. *Proceeding of the XXth Congress of International Association of Logopaedics and Phoniatrics*, 1986, Tokyo.
 - 29) Vogelsänger, G. T. : Experimentelle Prüfung der Stimmleistung beim Singen. *Folia Phoniat.*, 6 : 193~227, 1954.
 - 30) Waar, CH., Damste, PH. : Het fonetogram. *Tijdschr. Log. Fon.*, 4: 198~204, 1968.
 - 31) Wolfe, S. K., Stanley, O., Sette, W. J. : Quantitative Studies on the singing voice. *J. Acoust. Soc. Amer.*, 6 : 255~266, 1935.