Voice performances in relation to demands and capacity : development of a quantitative phonometric study of the speaking voice

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VOICE PERFORMANCES IN RELATION TO DEMANDS AND CAPACITY

Development of a quantitative phonometric study of the speaking voice

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VOICE PERFORMANCES
IN RELATION TO DEMANDS AND CAPACITY

Development of a quantitative phonometric study of the speaking voice

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan
de Universiteit Maastricht,
op gezag van de Rector Magnificus,
Prof. dr. A.C. Nieuwenhuijzen Kruseman,
volgens het besluit van het College van Decanen,
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Wat heb ik, wat houd ik?

Wat houd ik over na het overgaan?

En gaat dat ook weer over?

Of is er iets wat ik echt heb?

Herman de Coninck

Chapter

1

General Introduction

INTRODUCTION

Voice performance and problems with voice performance are often based on behavioural characteristics like vocal technique, hyper- or hypofunction of the vocal mechanism [5,11,16], and on physical parameters of the sound like intensity, frequency, timbre, sonority or breathiness [6,18]. However, parameters related to the general physiology of the subject involved play an important role. Therefore a thorough investigation of these typical medical aspects of the voice performance is indispensable in cases of impairment and handicap [2,3,19]. A good respiratory function is required which primarily depends on the overall health and fitness of the individual. Vocal fatigue may be the first symptom of a neurologic disease or neuromuscular impairment or weakness. Professional voice users may suffer from laryngopharyngeal reflux and other gastroenterologic conditions which may produce symptoms affecting their voice performances. The physician should take care not to overlook the patients systemic health because for example Sjögren's syndrome and systemic lupus erythematosus may affect the mucous membrane and the voice as well. Voice performance is also extremely sensitive for endocrine dysfunctions. There is no doubt about the significance of environmental aspects and external factors (air humidity or dryness and dustiness, background noise, room acoustics, required vocal output etc.) in this respect. As a consequence, analysis of voice performance needs to be based upon evaluation and measurements in real life situations and require a close cooperation between clinicians, experts in occupational health and voice scientists [19,20,22]. An Ear, Nose and Throat (ENT) surgeon is often consulted when problems with voice performance occur. Besides establishing a full medical history, the ENT surgeon will perform a complete ear, nose and throat examination and a laryngeal endoscopic evaluation. As indicated above, he must be aware of the fact that lung, neurologic, endocrine or other systemic conditions may result in voice disorders and that these aspects have to be integrated in the clinical care. However, some problems can occur in the interpretation of the clinical examination by the ENT surgeon. It is quite possible that morphological abnormalities are found on the vocal folds of subjects with a normal voice and without voice complaints. In contrast, sometimes no organic abnormalities can be observed in patients who have hoarse voices or complain about vocal fatigue. Also, a specific lesion of the vocal folds can induce vocal disturbances during normal or loud speaking or singing in one subject but not in another [8,13].

Apparently, discrepancies between morphology and function are not exceptional. As a consequence, specific examinations, including the objective assessment of the voice function are essential when the vocal apparatus is not able to fulfill voice performances in relation to demands and capacity. Voice function tests under laboratory and field conditions will provide important information about the voice performance and voice capacity. Objective voice measures, measures of phonatory ability and evaluation of vocal use will add information to help diagnose the disorder, to guide the therapy and to assess the results of intervention [1]. Reporting that a patient's voice performance

has improved without having performed acoustic measurements, is as dissatisfactory as reporting that a patient's hearing has improved without having an objective evaluation by audiometry to prove it [14]. As the speaking voice is of utmost importance to every human being, research should pay more attention to the natural voice conditions. So far, the assessment of acoustic aspects of the voice function is still under development and is not generally and routinely applied [7,23].

The research described in this thesis focuses primarily on the objective characterisation, qualification and quantification of the speaking voice performance. In addition three secondary goals are formulated. First, a standard procedure for the quantitative evaluation has to be established, including the definition of relevant parameters. Secondly, special attention will be paid to the environmental aspect of the voice performance. Occupational dysphonia will be differentiated into dysphonia induced by impairment and occupation induced dysphonia. Thirdly, aspects of voice capacity and professional suitability will be examined, as it is clear that specially in professional speakers voice performances and occupational factors seem to play a more crucial role than the medical diagnosis.

Chapter 2 begins with the general outline of the problem of occupational dysphonia and its recognition as an occupational disease. It may be questioned that occupational dysphonia exists and which professions may induce a voice disorder that directly and definitely causes occupational dysphonia. Is frequent or loud speaking a typical function in a certain profession and is this injurious to voice production? Available literature was reviewed for a definition of occupational dysphonia, for information on incidence and prevalence and by way of specific occupational facilities. It could be that those who run into voice problems in their profession, are poor and asthenic speakers from the beginning. However, occupational voice demands are receiving no attention and a premorbid poor voice capacity is not established. Many cases of dysfunction are labeled as occupational dysphonia, but more likely they are the result of the wrong choice of occupation.

Before giving an expert opinion on suitability or incapacity of a subject's voice performance, it is at least necessary to know the vocal demands of an occupation [4,24]. It is of importance that a good voice capacity is a prerequisite to an adequate job performance in some occupations. Therefore, the more precise the quantification of the vocal demand is, the easier it is to judge whether a subject with dysphonia will be successfully or unsuccessfully introduced or reintegrated into a certain profession. Chapter 3 describes the development of a portable instrument for long term voice monitoring in natural and occupational setting. The results of a precise and objective documentation of vocal demands in some professions, help to answer the question, whether a patient is capable of doing the "voice work" that will be required of him.

Vocal fold closure is an important issue regarding long term load of the larynx [9]. An

objective and non invasive method for the investigation of vocal fold closure is electroglottography. This technique has existed for many years. It is inexpensive and does not interfere with simultaneous measurement of other variables. Chapter 4 reports the development of processing the electroglottographic (EGG) signal in normal and pathological voices, the reproducibility of the data and the clinical applicability of EGG for vocal fold functioning.

Vocal fatigue, a clinical syndrome featuring hoarseness or breathiness and pain or discomfort in the throat, is marked by a strain on the voice while talking and a deterioration of the voice. Chapter 5 presents the results of objectivation of these complaints of vocal fatigue by acoustic analysis obtained using Computerised Speech Lab. It presents quantitative data by assessment of the sound performances and by the calculation of (ir)regularities in the EGG wave-form. Patients with a history of vocal fatigue as well as healthy subjects rated their pain and fatigue during the Voice Interval Test as well as during a regular working day.

Voice capacity can be expressed in terms of the ability to phonate at low and high intensities [10,12,15]. Speaking at high and low intensities is accompanied by a rise or decrease of the fundamental frequency and this is related to the effort of the laryngeal muscles in glottic closure and subglottic pressure[7]. To explore the possible relation between this involuntary pitch rise and vocal performance in normal subjects and in patients with voice complaints we have to do first a normative study in normal subjects. Chapter 6 describes this quantification of pitch rise in five different loudness levels of speaking in 125 women and 125 men.

In order to know whether pitch rise during high intensity speaking has predictive value for the individual's voice capacity, the above normal performances have to be validated in subjects with abnormal voices, i.e. superior and inferior voices. Chapter 7 reports about the impact of speaking intensity upon pitch in 65 professional speakers (strong voices) and in 15 subclinicals and 42 patients (poor voices). Of the last group diagnostic, pretreatment and posttreatment results are compared and the effect of the therapy is discussed.

In order to determine whether a (future) teacher is suitable for employment two groups of female teachers -one group of 20 subjects with and another group of 30 subjects without voice complaints- underwent functional testing of their speaking voice. The results of pitch and loudness performances of speech are described in chapter 8.

Next to laryngological investigation and determination of vocal performances it may be important to analyse how the voice is currently being used [15,17]. This clinical observation of voice production by visual and tactile identification of the vocal technique is still in the phase of subjective and individual evaluation [21,25]. It has hardly been described in literature, there is no uniformity in rating and description, and no

research has been done about reliability and validity. Primarily, it was our intention to investigate the effect of improper voice technique on voice performance, voice endurance and voice quality. However, this was impossible because experts did not agree on which subject's vocal use was adequate or inadequate. It is clear that this subjective evaluation is a topic for analysis and has to be improved and linked with objective voice measurements. The process of acquiring good speaking technique begins with diagnosing improper voicing technique. Chapter 9 describes our experience in evaluating vocal techniques.

The results of the research in this thesis are summarised in chapter 10. Suggestions for management of occupational dysphonia are presented.

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Chapter

2

**Occupational dysphonia:
definition, epidemiology and management**

ABSTRACT

For some activities a good voice is needed. It has always been supposed that everyone had a good voice and (loud and long) speaking was not perceived as an occupational strain. The importance of the voice is only recognised as soon as there are voice complaints.

A voice disorder may arise not only as a problem of voice quality but can also have psychological, financial and professional consequences. The impact of voice disorders in the active population is unknown because there is no general definition of occupational dysphonia and because this is not a recognised occupational disease.

More than 10% of people use the voice as a main tool for their professional activity and one to 20% of this group is at risk for occupational dysphonia. An overview of the epidemiology and the variety is described. In the total group of occupational diseases, dysphonia only represents a small part; minorities attract no attention and do not determine the policy and therefore there is insufficient prevention, no functional testing and deficient rehabilitation. Patients' need for expert care is increasing and the government and insurers now pay more attention to employment and economy measures. They become attentive also to the small ones so that distinguishing wrong choice of occupation from burnt-up voice and operationalising vocal stress and voice capacity become exciting challenges.

INTRODUCTION

In trade and industry and in the world of sports, ergometric studies are performed in order to determine the physical suitability for a certain task and to measure the physical strain involved in a certain type of work. However, speaking and talking in general for a long duration is usually not considered to be a physical exertion and is, therefore, not studied in a similar way as the previously mentioned physical activities.

In most occupations an average speech ability is sufficient. In a number of occupations extra skill and an appropriate speech apparatus are required. We estimate that in The Netherlands at least 1.5-2 million persons are working in jobs which have great demands on the voice. This applies particularly to teachers, instructors, educators, actors or certain service sector jobs such as salesmen, sales representatives, demonstrators, social workers, hotel and catering branch workers, civil servants, managers, politicians, etc.

In some types of occupational education (e.g. singers, actors, musicians, speech therapists) the students receive additional training in vocal use. In teacher training colleges little or no attention is paid to optimise voice capacity and vocal use.

In daily praxis otolaryngologists and speech therapists are regularly confronted with patients for whom it is difficult or even impossible to practise their occupation because they cannot meet the speech requirements that are involved in it.

It is our impression that in some cases this could have been avoided if a professional suitability test for vocally stressing work had been performed previously as not every speech apparatus can resist a specific vocal stress [43].

From the point of view of the patient, of phoniatrists and of speech therapists and even of insurance companies it seems to be evident that occupational dysphonia exists. If this was regarded as direct consequence of the occupation the exposure to this occupational hazard produces an occupational disease. Demonstration of this causal relationship will be very difficult because the patient needs to show that a particular disability is not the consequence of a wrong choice of occupation. Therefore, it seems mandatory to evidence a good voice capacity starting the job.

Speaking as an occupational strain

The use of the voice is a heavier exertion than one usually realises [9,19]. Anyone who speaks for some time at full volume soon finds out what an effort it really is. A strong voice requires a good larynx and a lung ventilation based on good action of the chest and abdominal muscles, chiefly of the diaphragm. Furthermore, a good vocal resonance and a bright vocal sound require a good shape and function of throat, mouth and nose.

The efforts involved in speaking can be split up into the straining of the vocal folds (the larynx) and the auxiliary musculature [46]. Vocal sound originates from a complex and dynamic interaction of various muscles throughout the body. As a consequence vocal pedagogy and voice therapy primary is based upon muscle training [38]. Parameters that determine the muscular strain at the level of the larynx are loudness, pitch and

duration of speech.

Parameters used for the definition of the vocal strain relate to muscular effort. Muscular effort is defined as a product of output and time. The exertion capacity is the maximum energy generated by a muscle per unit of time. The higher the required energy the sooner the muscle will be exhausted. Likewise, the longer a speech effort has to be sustained, the stronger the fatiguing effect on the muscle is. The maximum vocal capacity differs individually. Obviously a person having a strain capacity of 100 dBA will be able to sustain a speech effort of 75 dBA longer than a person having a strain capacity of 80 dBA. In other words, a smaller capacity means that fatigue occurs at lower phonation intensity.

The capability of producing large loudness variations is based on the anatomy and physiology of the larynx. For a considerable loudness variation obviously a good closing action of the glottis during phonation is mandatory. Incomplete or shortened glottis closure can sometimes be remedied through exercise, but in many cases the larynx leak is constitutionally determined; in other words, it is a physically determined limitation [39].

Table 1: Strain versus strain capacity.

strain	strain capacity
Strain = Capacity x Time	Capacity = $\frac{\text{Strain}}{\text{Time}} = \frac{\text{Loudness}}{\text{Time}}$

For the purpose of quantification of the performance load the required loudness (intensity of sound while vowels are pronounced) of the voice is taken as the main parameter [22]. In most conversations the intensity of sound is around 65 dBA (measured at 30 cm from the mouth). Teachers have to be able to sustain an intensity of sound of 70-76 dBA for many hours [8]. In particular for nursery school teachers a strong voice at the high frequencies as well is mandatory because in nursery schools noise levels vary between 75 and 80 dBA [49] and singing and expression are important elements of a child's education. When the voice is raised to a level higher than 85 dBA the speaker is shouting. This can occasionally be required to alert people to danger or when commands are given (police, soldiers, sports teachers, on a building site, freight handling). The degree of straining of the voice is not only dependent on the loudness parameter. The pitch is also a factor that has to be taken into account, but in speaking it is a factor of much less weight than in singing. This is because people use only a small part of the tonal capacity while they are speaking.

Figure 1: Phonetogram with speaking field in total voice range.

At higher frequencies the larynx musculature is strained differently [13]. The optimum pitch of the voice depends on gender and on individual factors such as the structure and the mass of the larynx. For a person with a bass voice it is more exerting to intonate 524 Hz than for a soprano.

Therefore, speaking loud at a high pitch produces a considerable straining of the voice [35]. This is known from persons whose occupation involves teaching, leading groups or delivering speeches. Beside the absolute loudness and pitch, variations of these parameters are also important. Controlled speaking with strong fluctuations in loudness and pitch implies an additional strain. Instability of the voice (with pitch breaks and creaky onsets) is an indication of loss of control and a symptom of overstraining [29]. Furthermore, the auxiliary musculature ought to be considered. The auxiliary musculature is here defined as the musculature of the oral and oropharyngeal cavity and respiration. A change of tone colour (for instance nasal, shrill or deep) imposes an unnatural burden on this musculature [47].

Debruyne [13] defines vocal fatigue as a symptom of imbalance in muscle activity and/or mucosa condition. There has to be balance in respiration energy by breath control and support, in resonation positioning by adjustment and accurate positioning of the vocal tract, and in vocal fold vibration by concerted action of glottis closing energy and longitudinal strain of the vocal ligament. Vocal fatigue is caused by metabolic changes in the muscle fibres and the nervous system [42,11]. This results in decrease of energy and decrease of co-ordination so that compensatory contractions appear which are not efficient and in fact undesirable.

Furthermore, there is the desiccation effect due to decreased hydration of the vocal folds which raise the threshold of phonation [52]. With increased amplitudes and faster and longer contact/closing pulses as the intensity of speaking is augmented the mucosal wave will increase in variability, the mucosa will get irritated and the mucosal wave oscillation will increase in cycle to cycle variation and so leads to hypervascularisation, swelling, nodules and oedema. Rhinitis, allergic hyperactivity will consequently make the mucosa more congestive and vulnerable so that a supple mucosal wave is interfered.

For an adequate assessment of this burden ambient factors should also be considered. Temperature and low relative humidity or the presence of any irritating dust substances, gases and vapours are significant for vocal function. Vilkman and Manninen [51] studied the influence of environmental factors on speech characteristics such as fundamental frequency, intensity, spectral and prosodic features, diadochokinesis and word repetition. Qualitative and quantitative differences were observed as a result of various exposure combinations. The fact that various speech characteristics behave differently in different environments indicates that it is essential to observe several parameters simultaneously for the description of a particular arousal and emotional status. The extremely complex interactive effects and the individual differences in coping strategy indicate that differences in voice analyses also might reflect different psychological states.

Adverse acoustic circumstances aggravate the exertion of the vocal organs. The acoustic conditions of classrooms require teachers to increase their vocal effort because most classrooms are too reverberant and the background noise affects speech production in order to maintain an acceptable signal to noise ratio. Van Heusden et al. [21] stated that vocal effort is simply adjusted according to how much effort is believed to be required for speech to be understood. Excessive vocal effort may result in vocal symptoms and voice complaints. Pekkarinen and Viljanen [31] measured Rapid Speech Transmission Index (RASTI) values in classrooms and they concluded speech intelligibility was not as good as desirable for rooms in which speech communication is the most important mode of communication. The absence of guidelines on the acoustic qualities of workrooms or classrooms reflects the subordinate general awareness of these phenomena as opposed to the abundance of building construction regulations related to lighting, energy consumption and ventilation.

Finally, intrinsic psychological factors have an impact on the vocal exertion, most of all when people are exercising an occupation where they are dependent on their voice.

Sensations of failure, anxiety and anticipated negative experiences induce physiological reactions on the mucosa of the vocal folds. The physiological reaction might change the timbre of the voice in particular, by drying of the laryngeal mucosa as a consequence of increased sympathetic activity [41]. Voicing is very sensitive to emotional arousal and psychological stress [37]. Our personal identity is strongly associated with our vocal image, i.e. the impression our voice makes on others. In every human the voice is subject to emotional effects. In a sensitive person stress brings about a change in the phonation pattern and as a result the vocal strain increases [3]. Prolonged stress is also commonly associated with increased muscle tension, particularly in the head and neck. These alterations may lead erroneously to the diagnoses of a mere muscular tension dysphonia [27]. The influence of live events has been shown to have an important effect on the ethiopathogenesis of functional dysphonia [15]. In classifications of functional voice disorders this element is revealed in terms like psychosomatic dysphonia [28] and psychogenic dysphonia [2] even as reason for incomplete glottis adduction. In psychogenic dysphonia it is often possible to elicit a history of stress and it must also be recognised that voice quality and voice production is distinctly abnormal in psychiatric conditions such as schizophrenia and depression. Finally, voice disorders also cause a rebound effect of emotional stress and anxiety as dysphonia has an impact on a person's reputation and ability to meet professional commitments.

Table 2: Summary of speech-straining factors.

• speaking with high loudness (more than 70 dB)
• speaking at a pitch outside the normal range
• speaking for a long time
• speaking with strong intonations (more than 6 semitones)
• speaking with an unnatural tone colour
• poor surrounding acoustics
• dusty workroom (eg. chalk dust), gases, vapours
• a workroom with a strongly deviating temperature or a dry atmosphere and inadequate ventilation
• smoking and consumption of alcoholic drinks
• speaking while affected by strong emotions

So far we summarised the most important occupational factors underlying the development of professional dysphonia. The strain injury is caused by the vocal exertion itself but also by the quality of working condition, psychological factors and inadequate diagnosis and neglected treatment of early symptoms. In the past the majority of occupational voice disorders were classified as functional disorders; at present it seems justified to classify these voice problems as organic and in clinical practice more attention ought to be paid to minimal anomalies and job related risk factors which interfere with quality of live.

Diseases of the voice induced by over-exertion and occupational dysphonia

Complaints arising of a disproportion between the vocal capacity and the work load (strain) are induced by over-exertion. The vocal capacity may be small due to genetic predisposition but it may also be reduced as a result of diseases or defects (for instance disorders of the vocal folds, chronic obstructive pulmonary disease or COPD). In table 3 we have summarised the principal causes of a reduced vocal stress capacity [7].

Table 3: Causes of a reduced vocal stress capacity.

• congenital factors
• ageing effect
• chronic infectious diseases of the respiratory tract
• organic disorders of the vocal folds
• lung ventilation problems
• medication which inhibits the production of mucus
• a predisposition to airway mucosa hyperactivity
• a decreased general fitness
• wrong speaking and voicing techniques

In the following we will focus in particular on persons having a small voice and persons with a poor loudness or pitch range apparently without organic laryngeal disease. However, upon a more precise examination focused on function an incomplete or shortened closure of the glottis can sometimes be detected. This may be the result of a wrong vocal technique but mostly it is the result of an imperfection of the larynx. The treatment and prognosis for a deficient glottis closure will mostly be different than for

a misused or abused voice organ.

Persons who have a reduced vocal stress capacity will be more likely to show decompensation than those who possess a strong voice. Within certain limits the vocal capacity can be expanded through exercise and training but fundamental changes will not come to pass.

A frequently occurring overstraining-induced disease in women is the formation of vocal fold nodules. A wrong use of the voice and vocal abuse means that the vocal folds are subjected to too much strain. When this vocal effort is reduced, this overstrain-induced "physiologic swelling" will disappear (provided that the overstraining has not been going on too long). This problem is attributable in the first place to excessive use of the voice rather than to a wrong vocal technique. From this analysis it can be concluded that a wrong vocal technique can result in vocal fold nodules but only if the particular person speaks excessively and/or loud. Exceeding use of the voice will always result in complaints. Depending on the individual strain capacity of the larynx the amount of exertion varies interindividually.

In men chronic overstraining will more often manifest itself in the form of a vocal fold polyp. Excessive use of the voice, in short heavy bursts, can result in this mucous membrane lesion. This pathological phenomenon cannot be remedied even if the patient refrains from further abuses of his voice nor will the polyp disappear [40]. A laryngitis and hyperaemia will probable disappear when the patient withholds his voice. A polyp can only be removed by (micro)surgery. After surgical intervention the voice will mostly return to normal because the polyp has not originated from a wrong vocal technique, but by excessive use (phonotrauma): shouting, singing, chanting, cheering, etc. Less heavy overstraining for a long period of time may result in chronic laryngitis (which may be accompanied by the occurrence of premalignant epithelium anomalies such as leucoplakia and/or ulceration). The contact ulcer is a chronic epithelium defect, the edge of which shows hyperplastic accretion epithelium with a minor inflammation reaction in the submucosa. This ring-shaped anomaly is mostly present at the medial side of the processus vocalis, where the arytenoids come together.

In general, the following adverse factors can be mentioned as contributing to vocal overstrain:

- Tobacco, alcoholic drinks and certain medicaments
- Psychological and behavioural factors: a person who is manic, extrovert, self-assured or enthusiastic will be more inclined to overstrain his larynx than someone who is depressive, introvert or asocial. Some people tend to manifest themselves habitually as 'cock of the walk'; such people will benefit greatly from having a sturdy larynx.
- Ageing: At the age of 60 a person's maximum speaking volume usually is not more than 80 dBA. Even if the occupational requirements remain the same for many occupational speakers a time will come when the vocal strain exceeds the capacity due to the effects of the ageing process. The strain-bearing capacity inevitably declines with advancing age, due to mucous membrane dehydration and incipient atrophy which will affect the closure of the glottis.

Knowing these causes and factors it is important to determine the relation between the voice impairment and the occupational demands and circumstances. Occupational dysphonia is caused by circumstances and demands of the job. Even good voices can be ruined in certain working conditions. Looking at the definition of occupational hearing loss (= sensorineural hearing impairment caused by exposure to high intensity noise in the workplace) the definition of occupational dysphonia is comparable but remains unclear in certain aspects as it has to be contrasted against dysphonia induced by an impairment. Literature and epidemiological data do not clearly define the mentioned difference and they seem to be confused quite often.

Epidemiology of voice impairment: a review of the literature

Reviewing the literature of Dutch studies, the following relevant results were found:

- In 1984 a total of 496 persons (0.8% of the overall number of incapacitated persons) were registered by the GMD (Communal Medical Services) as incapacitated and unable to work due to a disorder of the upper respiratory tract, larynx or vocal organs [17].
- Van der Putten [34] examining a random selection of 1000 incapacitated public employees found 193 educational workers of whom two (0,5%) were incapacitated owing to vocal fold pathology.
- In a study of incapacitated subjects between 1982 and 1988, Groen and Buekers [17] analysed 2371 ABP (General Pension Fund for Public Employees) incapacitated cases with 'Disorders of the (upper) respiratory tract' and recorded larynx carcinomas (n=161), chronic laryngitis (n= 476)) and head & neck symptoms (n=487). This resulted in groups of 52, 16 and 41 incapacitated cases because of voice disorders over a period of 7 years with a virtually equal sex distribution. Within the total group of 2371 ABP incapacity pension beneficiaries, the educational workers account for about 25% and most of these persons were aged between 45 and 59.
- Daemen and Schaapveld [12] interviewed 50 educational workers (with a career record of not more than 6 years) and 50 students (receiving a teacher training) about voice complaints. Voice and throat complaints were recorded in 10 and 12% respectively; 45% and 39% stated that they never had such complaints.
- Among the 133 patients who presented with voice and throat complaints at the ENTclinic 50% had an occupation which involves intensive use of the voice; of these, 40% are teachers, 75% are younger than 40 and 70% are of the female sex [26].
- Van der Broek [5] could not find epidemiological data of voice disabilities in literature of occupational medicine. He accounts the discrepancy to general ENT and phoniatic experience to the lack of function based medical inspection.
- Peters et al. [32] report in that 47% and 45% respectively of all new patients with voice disorders are practising an occupation which involves intensive use of the voice. 65% of the patients are female and 35% male; 50- 55% of the patients exercise an educational occupation.

- Van Poppel and Kamphuis [33] made an inventory of health risks in educational occupations. Teachers mostly complain of fatigue, nerves and pains. In a quantitative ranking of chief complaints, voice disorders take the 11th rank (10%). They report two remarkable phenomena: All complaints increase with age except voice complaints, which occur more frequent in younger teachers and secondly, educational workers relate their health complaints significantly more to their occupation (37%) than employees in other sections (23%).
- The USZO (Disability insurance for civil servants) has no information about the incidence and prevalence of occupational dysphonia because of registration and classification by diseases and not by impairments.

Figures from other countries may not be directly comparable to Dutch figures (differences in selection and voice training of student teachers, terminology, insurance system etc.), yet it is worthwhile to take a look across the borders. Reviewing the literature of other countries the following relevant results were found:

- In Germany several clinics reported data about occupational dysphonia. Unger and Bastian [50] analysed a group of 690 patients having an occupation with a major speech element who presented at the ENT & Phoniatic Clinic: 69% are occupational workers, 5% are actors and 26% are saleswomen, officers or executives, 71% are women; 60% are younger than 35; 74% of the group does not present an organic disorder (*funktionelle Dysphonie*). Pahn et al. [30] observed chronic hoarseness in 45% of all occupational workers. Heidelbach [20] reports in a series of 6500 voice disordered patients, the sum of 22.500 days of sick leaves. Gundermann [18] finds an occupational dysphonia (dysphonia resulting from overstraining the voice) in 7-8% of the educational workers.
- Janvier et al. [23] made a retrospective study on absence due to occupational dysphonia using data from the Belgian Department of Health Administration. The sample includes teachers who were absent during the period 1988-1992. The problem was no diagnosis such as voice disorder exists and they could only retain the diagnosis aphonia and laryngitis. Their results showed that ten percent of the teachers regularly had voice problems but only one percent was absent. Of the absentees 75 % was female, 66 % was between 31 - 50 years of age and the average absence was two weeks.
- Enderby [14] reviews information regarding the size of the speech and language impaired population in the United Kingdom. Information relating dysphonia concludes that there is annual incidence of 28 per 100.000. She suggests to record more details concerning a particular dysphonia except data on occupational dysphonia.
- In the USA Cooper [10] concludes from questionnaires presented to different occupational groups that educational workers have the most voice complaints (58%). In a random selection of 432 students he found dysphonia in 21%. In a group of 267 priests/preachers he found 'only' 9% with voice complaints. Sapir et al [36] analysed 237 questionnaires obtained from female teachers (84% return

rate). Over one half of the teachers reported multiple symptoms of vocal exertion. Of these teachers, over a third reported that their voice problems interfered with their ability to teach effectively, nearly a third indicated that they had to be absent from work because of voice problems, a fifth reported that they sought medical advice, and nearly a fifth indicated that their voice had been a source of chronic stress or frustration. Smith et al. [44] collected 242 (of 266) questionnaires of primary and secondary school teachers and a non-teacher control group including a random sample of 178 employed adults. Teachers were more likely to report to have voice problem (15% vs. 6%). Over 20% of teachers but none of the non-teachers had missed any days of work due to a voice problem. These findings suggest that teaching is a high risk occupation for voice disorders and that this health problem may have significant economic effects.

- In Canada Gotaas and Starr [16] received questionnaires from 250 (of 520) teachers and 80% experienced vocal fatigue. Vocal fatigue was defined as changes in vocal quality, pitch, loudness or effort that begins to occur as the process of speaking progresses during the working day and usually disappears by the following morning. The severity of vocal fatigue episodes were judged to be mild in 58 % of the teachers. Those who fatigue infrequently had milder episodes than those who fatigued frequently. Severe fatigue episodes occurred infrequently (11%) and do not appear to be closely related to the frequency in which fatigue was experienced. The authors interpret the data as indicating that neither the amount of time, nor the employed loudness appear to be solely responsible for vocal fatigue but that teachers who fatigue are more likely to perceive (speaking) situations to be tense and stressing, thus, increasing their proneness to respond with higher levels of anxiety and changes in vocal behaviour.
- In Australia Kitch and Oates [25] suggested a number of trends derived from a study in vocal fatigue in 20 volunteer subjects (10 actors: 7 female and 3 males; 10 singers: 8 females, 2 males) selected through random sampling of active professionals in the Melbourne area. All subjects had experienced vocal fatigue, 40% of the actors and 20% of the singers reported experiencing vocal fatigue frequently when performing. The actors rated power aspects and singers rated pitch range and flexibility aspects as most affected when vocally fatigued. They suggest further studies using objective measures so that vocal fatigue can be identified and to delineate what levels of vocal fatigue are within normal limits and what levels may place them at risk.

In view of these percentages, the question arises: 'How many people (educational workers) have to give up their job or have to change occupation as a result of voice problems?' Answering this question is almost impossible because existing studies are based primarily on clinical (nonrandom/biased) patients, small sample sizes, or do not include a comparison group. There are also many factors which interfere:

- it is unclear what percentage may have taken early retirement as a result of their health problem and thus were not available for interview;
- change of job, occupational discipline, scope of job; (external) factors such as

- group size, space/room, acoustics, noise level and tools;
- voice education during training or vocal therapy; people who develop voice problems in the initial stage of their appointment will not be included in the incapacity for work figures because they are retrained for another occupation;
- not all voice disorders result in incapacity for work and/or absence from work; some persons will have an opportunity to change job while others can compensate their restrictions reasonably well (for instance by making use of a voice amplifier).

Research of this nature typically requires an epidemiological approach and large sample sizes before results are forthcoming.

We agree with Janvier et al.[23] who stated that in the present educational and occupational orientation policy no allowance is made for vocal aptitude aspects involved in the teaching profession. Persons having little vocal aptitude should adjust their choice of occupation.

Because of the method of registration it is difficult to gain insight into the group of the occupationally disabled suffering from a voice disorder, for it is not the voice problem (disability) but the cause, the disease (disorder) which is coded. The ABP Act only recognises incapacity for work on account of proven diseases and this obliges the examining physician to designate a disease (e.g. depression, arthrosis deformans, laryngeal paralysis etc. from the symptomatology of his own speciality) as the diagnosis. The functional voice disorders are not recognised as such diseases. Yet it can be stated that within the overall population of the occupationally disabled the vocally handicapped constitute a very small group (less than 1%). It is clear that the concept of vocal strain and voice capacity is defined insufficiently.

Management of vocal incapacity

A few examples will illustrate the variety of vocal incapacity at work:

- A 30-year-old sports instructor cannot practise his occupation any more due to chronic voice and throat complaints and insufficient voice volume;
- A 46-year-old teacher and conductor has been aphonic for eight months already (vocal and alcohol/tobacco abuse);
- A 50-year-old public relations manager who has been suffering from severe hoarseness and a rough voice for almost a year cannot perform any more: leading meetings, receiving groups of people, making speeches, giving press conferences etc. have become impossible for him;
- A 26-year-old female singer cannot sing any more, is unable to fulfil the contracts with her manager and her orchestra and loses her income;
- A 32-year-old primary school teacher cannot teach in a classroom any more due to vocal disability. Provisionally she is working on a half-time basis with small groups and individual children;
- A 20-year-old student of a teacher training college is no longer able to carry out the practice training assignments because of voice and throat problems;
- A 28-year-old female social worker cannot guide group activities any more

because of her hoarse and weak voice.

A few contrasting examples:

- A 45-year-old teacher who has undergone laryngectomy has been giving lessons again in the classroom on a part-time basis for six years already;
- A 47-year-old teacher with a unilateral larynx paralysis works full-time, partly as a practice traineeship co-ordinator, partly as a teacher;
- A 38-year-old salesman who has been suffering from severe hoarseness since a therapeutic microlarynx surgery, is now working at the financial accounting department of the same concern;
- The harsh and rough voices of Bonnie Tyler, Harry Belafonte, Tom Waits, Joe Cocker are commercial successes instead of disordered voices of defaulted singers;
- A 35-year-old female teacher with a unilateral larynx paralysis gives lessons five mornings per week with the help of a voice amplifier.

There is no single cause for vocal incapacity: with cancer of the larynx or unilateral vocal fold paralysis some people may sustain vocal efforts, while on the other hand other people with muscle misuse voice disorders are handicapped employees. At present time there is no test that will measure objectively the degrees of impairment from the many varieties of speech disorders. Therefore, the American Medical Association recommends in their fourth edition [1] to evaluate the speech impairment by examining the audibility, intelligibility and the functional efficiency of speech. Judgement of the patient's speech capacity is made by a classification chart of the three criteria. The degree of impairment of speech is an equivalent out of a table and this impairment of speech can also be transmitted in a fixed % impairment of the whole person. Aspects as voice quality, pitch and melodic variation are not evaluated. Intensity or volume are examined indirectly, because audibility is based on the persons ability to speak at a level sufficient to be heard.

Recognizing that the demands on a speaker and his/her voice are different, there is no single threshold or value that determines occupational incapacity.

Instead of joining a next definition, disorder or syndromes it seems more relevant to practice with good and clear classifications of voice use. Koufman & Isaacson [24] presented four subgroups:

- Elite vocal performer (actors, singers, broadcasting professionals): even slight vocal difficulty may cause serious consequences.
- Professional voice user (teacher, priest, telephonist): moderate vocal difficulty would prevent adequate job performance.
- Nonvocal professional (lawyer, physician, manager, seller): they could not perform their work properly if suffering from severe dysphonia.
- Nonvocal nonprofessional (employee, labourer, factory worker): they would not be prevented from doing their work if experiencing vocal disability.

The duration of symptoms before consulting a doctor is correlated with the level of vocal use. Otolaryngologic evaluation and voice assessment is also correlated with this

level.

If someone has chosen an occupation which involves a vocal burden and he or she is affected by a decompensation of the vocal organs at an early stage owing to small vocal capacity, then there is clearly a case of a mistaken choice of occupation.

Figure 2: An average voice (shaded area) has a tonal range from 18-30 semitones (1,5 - 2,5 octaves) and a speaking voice volume between 20 and 30 dBA. A small voice has a lower performance than this (inside the meanwhile a large voice can do better (outside the mean).

Such early disability could have been predicted by means of laryngostroboscopic observation and voice function measurements Södersten [45], Sulter et al. [48]. The wrong vocal technique should be seen here as a consequence of a primary unsuitability. The most likely cause of the early decompensation is a small capacity of the voice, rather than a disease or defect. This is usually correlated with minor deviations in the anatomy or physiology which do not present problems at the level of ordinary daily conversation, but can soon be the cause of problems if the person's occupational practice involves prolonged and near maximum voice efforts.

It is a wide-spread error that this problem always completely can be remedied through logopaedic treatment; after all, not any kind of logopaedic treatment could ever transform a poor voice into a strong one. Moreover, we know from voice and singing education that improvement and mastery of the technique -for people gifted with excellent voice capacities- requires daily training and practice which have to be continued for years [3, 4, 53]. People who are required to do so often find it easier to learn to play a new instrument than to train their own (singer's) voice. In such cases of wrong choice of occupation it is unlikely that the incapacity for work status will be permanent because there are possibilities to look for other suitable work.

Table 4: The distinction between wrong choice of occupation and burnt-up voice.

wrong choice of occupation	burnt-up voice
• to be forseen	• not to be forseen
• early incapacity	• functioning well for years
• wrong technique is a result	• improvement of technique is useful
• no occupational incapacity	• partial occupational incapacity because of occupational disease

If signs of a voice overstrain disease occur in mid-career prescription of a period of rest for the voice may be indicated. In many cases this will not offer a fundamental solution at all, but merely a postponement of definitive measures. Such measures could be a reduction of the voice-exertion or assignment of a task which requires less voice volume, for instance by shifting from classroom tuition to more individual tuition (task hours, remedial teaching, post of deputy principal). In some cases it will be possible to achieve a reduction of the vocal burden by an improvement of the working conditions, such as better climate control, improvement of the acoustics or a ban on smoking. In specific cases auxiliary equipment (amplification equipment) can offer a solution, in particular if the affected person has a limited voice capacity of his or her own.

If there are symptoms of wrong vocal use, logopaedic intervention will be an option. These patients often benefit very much from a temporary and specific vocal technique training under the direction of a speech therapist. Their vocal use will become more selective and less strained, which they will experience as an enhanced vocal strain capacity.

In many cases, however, the diagnosis of a vocal exertion disease implies that the disability and a reduced degree of occupational fitness has to be accounted for. Auxiliary tools such as a voice amplifier are relatively cheap if they enable the user to work

more and/or longer. In some cases the occupational medicine service steps in and requires adaptation of acoustics and climate control, which can have a very beneficial effect in terms of vocal effort.

CONCLUSIONS

In the context of Employment and Health, more particular in the relation between employment and voice impairment there are some data which are of particular relevance in this context.

There are very great differences between the studies carried out in the various countries. Definitions, nomenclature and operationalisation are still developing.

It would be appropriate to devote more attention to the speech strain involved in the practising of an occupation, in the selection procedures, but also in the form of skill promotion and vocal coaching in the occupational training.

Vocal incapacity is not a single ability but it is a performance related to vocal demands: the development and integration of quantitative and functional diagnostics is a highly necessary challenge.

In the rehabilitation of professional voice users an interdisciplinary approach is desirable: ENT for the medical problems, occupational medicine for the environmental factors and successive reintegration, a speech pathologist for the voice evaluations, adjustment of the voice technique and augmentative speech amplifying aids.

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Chapter

3

Vocal load as measured by the voice accumulator

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ABSTRACT

Voice disorders related to occupation and work environment are often observed in ENT consultations. Advising these patients requires not only the investigation of their vocal capacities but also knowledge about their vocal load. The patient will name extreme demands as the reason for vocal problems whereas the employer will want to know if the patient is capable of doing the work required of him. For an objective measurement of vocal load, a voice accumulator has been developed. This portable instrument records total speaking time and sound level over a period of several hours. The data can be transferred to a personal computer which analyses voiced time (s) between 60 and 112dB(A)s. Thus, more precise and objective documentation of vocal demands in some professions can finally be obtained. With these results, it is possible to monitor vocal ability or disability during vocal rehabilitation.

INTRODUCTION

In a phoniatric clinic, the amount of voice disorders related to vocal load is substantial. It is generally assumed that persons who have to speak loudly are at greater risk for throat and voice problems [14]. All patients with voice complaints report a great vocal load; however, many people with such a load (e.g. actors and singers) do not suffer from any voice complaints, which suggests a poor correlation between vocal load and voice complaints. Quantitative data dealing with vocal load and vocal use are sparse. Studies of vocal use in natural conditions are difficult to obtain, and most research analyses recordings in successive measurements during a day [5].

A device to record speaking time has been described by Watanabe et al. [6], but these registrations all neglect an important parameter of vocal load, i.e. the intensity of vocal use. Objective measurements of vocal load is very important not only for prevention of disorders and for decisions regarding vocal ability, but also for curative vocal rehabilitation and counsel of patients in restarting their job [7].

For such documentations, we developed the voice accumulator, a portable instrument that registers the duration and intensities of phonation during 12 h. In this article we present the method and results of vocal load measurements registered in a vocational setting.

INSTRUMENTS AND METHOD

To measure speech, the voice accumulator had to fulfill the following conditions:

1. Registration of phonation durations and intensities of an advisable time period of about 12 h. Intensities of phonation were preferred to frequencies because of the closer relationship between intensities and vocal load [8, 9].
2. Ambulant registration (wireless and battery supplied): mobility was required at the place of work of many subjects (fig. 1). From a technical point of view, these criteria were applied:
 - a. linearity of the microphone in the total intensity and frequency span, and
 - b. insensitivity of the microphone to other voices and environment noises.

The functional units of the voice accumulator are presented in figures 2 and 3. To measure voice intensity, a span of 50 dB(A) [60-110 dB(A)] was necessary [10, 11], which corresponds to a microphone output between 0.1 and 100 mV. The analogue signal was filtered (12 dB/octave A weight filter); the RMS was converted to DC and subsequently amplified and fed into an 8-bit AD converter at a sample frequency of 1 Hz. The digital signal was then stored in a solid state memory (128 kB). The entire data acquisition process was controlled by a CPU (type 80C31), and the processing software stored in 16-kB EPROM.

After the measurement, the voice accumulator was connected with a personal computer for analysis of the data; the analysis of a 6-hour registration required approximately 10 min.

Figure 1: The voice accumulator in operation with head microphone and accumulator (amplifier, ADC memory and battery pack) in the bag (total weight 600 g).

Figure 2: The azM voice accumulator measuring 15 x 9 x 4 cm (a); the battery pack (b), and microphone (c).

Figure 3: Diagram of the voice accumulator and microphone.

The subjects wore the voice accumulator during work. The voice accumulator was initialised and calibrated with a laptop computer (C286LT), using a Brüel & Kjær sound level meter (type 2231) 30 cm from the mouth. The microphone (Sennheiser MKE 48 PU) was adjusted and attached in such a way that the loudness on the sound level meter was equal to or within 1 dB(A) to that of the voice accumulator.

The feeding unit and the voice accumulator were worn in a hip-bag for registration the entire day. Subjects' voices were measured for a minimum of 3 h (part-time jobs), most for a period of 5-8 h.

The accumulator scored the loudness every second during registration. The dB(A) scale was divided in intervals of 2 dB(A), beginning at 60 and ending at 112 dB(A). For reproduction of the data we clustered 3 intervals of 2 dB(A), resulting in 10 intervals:

1.	<60	dB(A)	
2.	60-62-64-66	dB(A)	silence-quiet speech
3.	66-68-70-72	dB(A)	
4.	72-74-76-78	dB(A)	
5.	78-80-82-84	dB(A)	loud speechinstructions
6.	84-86-88-90	dB(A)	
7.	90-92-94-96	dB(A)	
8.	96-98-100-102	dB(A)	screaming-yelling
9.	102-104-106-108	dB(A)	
10.	108-110-112	dB(A)	

It was possible to obtain a list of vocal load for each subject with the distribution of the successive intensities vocalised in dB(A) divided into arbitrary time periods.

To facilitate interpretation, vocalised intensities were defined in 3 categories:

- 60-72 dB(A) (silence - quiet speech)
- 72-90 dB(A) (loud speech - instructions)
- 90-112 dB(A) (screaming - yelling)

By summarizing all the measurements of different subjects according to occupation, it is possible to obtain the vocal load profile of any occupation, specified as necessary, e.g. for teachers in general, primary school teachers, secondary school, high school or sports teachers etc. When vocal demands placed on an individual are to be defined, the individual's vocal behaviour can be measured and compared with the normative data.

APPLICATION AND RESULTS

Longer registration periods increased the validity of the scores. Reproducibility was good; it was controlled at 5 registration periods exceeding 5 h in a speech therapist

(fig. 4) and 3 registrations of more than 3 h in a youth leader (fig. 5). We asked the subjects to rate all their activities during registration in terms of the intensity of vocalisation. Whereas lesser vocal load appeared to be associated with more time in soft intensities, greater vocal load was associated with voice intensities greater than 72 dB(A).

Figure 4: Reproducibility scores (n = 5) of duration of vocal use at various intensities measured in a speech therapist.

Figure 5: Reproducibility scores (n = 3) of duration of vocal use at various intensities measured in a youth leader.

We also asked some subjects to annotate the kind of activities and intensity of voice used at fixed intervals of time during the measurement. The subjects' own ratings of their voices corresponded well with the objective measurement, which we verified by measuring some subjects in the first or the last minutes of the registration, also using the B&K sound level meter. In analysing the data we assessed the same voice use. These results affirmed the voice accumulator as an indicator of real voice performance.

A further possible point of interest is our accumulation of data for several occupations without any vocal use, e.g. a software programmer, an author editing and reviewing articles, and 2 bookkeepers (fig. 6). Except for a few minutes of conversation and phone calls, there was no phonation with intensities above 60 dB(A). The accumulated data of the vocal loads of various occupations are shown in figures 7-18.

Figure 6: Bookkeepers (n = 4).

Figure 7: Primary school teachers (n = 8).

Figure 8: High school teachers (n = 6).

Figure 9: College teachers (n = 4).

Figure 10: Special education teachers (n = 6).

Figure 11: All teachers (n = 24).

Figure 12: Sports instructors (n = 6).

Figure 13: Swimming instructors (n = 6).

Figure 14: Nurses (n = 7).

Figure 15: Receptionists (n = 5).

Figure 17: Kindergarten teachers 9n = 6).

Figure 18: Speech therapists (n = 7).

Our results seem to confirm general expectations and predictions, e.g. that sports instructors have the greatest vocal load, while bookkeepers appear to lead a life in silence. Among these quantifications some surprises also arise, such as the low vocal intensities of speech therapists, receptionists and telephone operators. These categories probably require a great deal of speech, but phonation in these cases consists predominantly of individual communication at soft intensities. Another remarkable finding was that vocal intensities during work activity were lower than the subjects themselves had expected. This should be noted by professionals helping patients who attribute their voice (throat) complaints to a great vocal load: patients, in particular those suffering from voice disorders, generally overestimate vocal strain.

DISCUSSION

As already mentioned, this article describes the possibilities and results of continuous registration of vocal use during work. This 'on-the-job' measurement of the duration and intensity of vocal use reveals accurate quantification of vocal demands. These data about the vocal load of occupations may be of help in rehabilitating patients with voice disorders.

Teaching appeared to be the vocation with the greatest vocal load in our population. It is interesting to compare the results of teachers with those of blue-collar workers, drivers and engineers. As yet, these professions are underrepresented in our patient group and have therefore not been investigated. The vocal performance of actors is also noteworthy: this group lacks voice complaints due to natural aptitude, vocal training, sustained warm-up and vocal hygiene.

Intensities above 90 dB(A) were rare and, where present, only lasted 1 or 2 s. In view of the vocal load of teachers and speech therapists, the lack of vocal training involved in the professional training of teachers is surprising. Teachers' vocal problems

demand more attention: firstly because of the higher demands placed on their voices and secondly because vocal ability is a neglected parameter in career choices and during training.

Difficulties in recording very soft intensities [<60 dB(A)] as well as the fine line at 55 dB(A) between silence and speech can be resolved by connecting a contact microphone or glottographic device, which also exclude noise coming from the environment.

As it was not our intention to collect exhaustive records of vocational voice behaviour, we recommend the voice accumulator as a possibility for accurate representation of voice use in individual cases, of exact demands in specific situations. The accumulator can also be used in achieving further objectives, e.g. when used as a control parameter: in voice therapy or voice reduction programs; in studying the relationship of voice use to other factors such as emotional stress and medication; in measuring the speech of stutterers during different phases of therapy, and for monitoring speech in language therapy and linguistic interactions.

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Chapter

4

**Characterization
of the electroglottographic waveform:
a primary study to investigate
vocal fold functioning**

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ABSTRACT

To objectify the vocal fold functioning we opted for a method of processing the electroglonographic (EGG) signal. This study with 7 normal and 12 pathological voices presents the results of measurements over the chest register as a function of voice intensity and frequency. Reproduction measurements show that at least 5 measurements per intensity/frequency pair are needed to get a reasonable estimation of the EGG parameters. The averaged results over about 20 measurements in the chest register showed differences for some parameters for subjects in the most different categories. To get more consistent results we recommend to improve the measurement protocol and adjust the parameters.

INTRODUCTION

Objective determination of vocal fold functioning needs a technique that measures vocal fold movement discriminatively and reproductively. The measurement should sufficiently discriminate to reveal the differences between different modes of vibration of the folds. For instance, the difference between an extremely hoarse voice and a clear one would have to show up in measurement results. The resolution, i.e. the smallest difference in voice quality that can be detected, should satisfy the needs of the user.

The use of the electroglottographic (EGG) technique for the measurement of vocal fold movement has been reported extensively in the literature [1, 2, 4-6, 9-11, 13, 14]. Other measurement techniques like photoglottography [6] are described in Baken [3]. Efforts to model voice production can be found in Baken [3] and Titze [15]. We opted for the EGG measurement technique for several reasons. Similar to acoustical measurements, the EGG technique is noninvasive as no measurement sensors (that affect the normal production of voice) are introduced into the mouth. This is of the utmost importance because changes in the acoustical impedance of the vocal tract directly influence the functioning of the vocal folds [3, 6]. The EGG signal is relatively simple to process in comparison with the acoustical signal. In spite of this, no extensive signal processing of the EGG signal is reported in the literature. Furthermore, the technique is now readily available and relatively cheap. On the other hand, the EGG signal reflects impedance fluctuations of multicausal origin, of which several most likely do not reflect the functioning of the vocal folds. Nevertheless did we find it worthwhile to put some effort in the processing of EGG signals in order to find out more about the relationship between the signals and the functioning of the vocal folds.

In this article we present the experimental setup and methods as well as the results of a primary study with different qualities of voices. With regard to the parameters the reproduction of measurement results has been examined as well as differences between voices.

MEASUREMENT SETUP AND METHOD

Next to the EGG signal, also the acoustical signal is measured using a microphone. The experimental setup is given in figure 1.

The acoustical signal is picked up by a B&K microphone and preamplifier, type 4003, fixed at a distance of 20 ± 1 cm in front of the mouth. The microphone signal is fed by a B&K type 2812 two-channel preamplifier and microphone power supply. The output of the preamplifier is fed into a self-made frequency/ intensity meter. The signal intensity is derived from the microphone signal and displayed in dB (A) on the frequency/intensity meter. The intensity [dB (A)] has been calibrated using a distance of 30 cm from mouth to microphone.

The distance at which we have been measuring was 20 cm to obtain an optimal signal-to-noise ratio [background noise 50 dB (A)]. This amounts to about 5 dB (A) more

intensity in comparison with a distance of 30 cm for the intensity range of 70-100 dB (A). The data presented here refer to the noncorrected values.

The EGG signal is measured using a Fourcin laryngograph (EGG meter), type Laryngograph, serial No. 86011 70.

Figure 1: The experimental setup.

1 = electrodes; 2 = microphone; 3 = power supply; 4 = laryngograph;
5 = alpha monitor; 6 = computer & graphics monitor; 7 = frequency / intensity meter.

The frequency/intensity meter displays the frequency in hertz of the sound wave on the lower display. Frequency is derived from the EGG signal. The signals from the frequency/intensity meter are read into the computer. The analog-digital converter digitizes the data. Rates for the acoustical and EGG channel are 39.2 and 19.6 kHz, respectively. Digitized data can be saved to file after making a recording.

Measurements of the vocal fold vibratory pattern (via the EGG signal) are done as a function of intensity and frequency in the chest register. Simultaneously a recording of the acoustical signal is made. The measured frequency span ranges for men from 100 to 200 Hz, for women from 190 to 282 Hz. Intensity ranges for men and women from 60 to 100 dB (A).

On the subject's neck a collar with the measurement electrodes is fixed. The subject is asked to produce an open [a] as in the Dutch word 'maan'. He has to sustain this sound during at least 2 s at constant intensity [within 2 dB (A)] and frequency (within 2 Hz). The subject is provided with feedback on the phonated intensity and frequency by watching the frequency/intensity meter display.

In an attempt to characterize the EGG signals we have chosen a pragmatic approach. After filtering and averaging the EGG, those parameters are extracted which are expected to be discriminative for different modes of vocal fold vibration. Different modes of vibration can in their turn be associated with various classes of voices (e.g. certain pathologies, trained singers' voices). Note that the modes of vocal fold vibration depend heavily on the frequency and intensity (loudness) of phonation [10]. This has to be taken into account when measurement results are to be compared.

The EGG parameters have been calculated after normalization in horizontal (time) and vertical (amplitude) direction. The jitter and shimmer factors are commonly seen in other literature [2]. The shape factor is a parameter that comprises both jitter and shimmer. The crest factor gives an indication of the peakedness of the EGG, and the speed quotient is the quotient of the maximum and minimum speeds in the EGG.

In addition to these we have defined parameters that are related to the properties of the rising flank that represents the closing phase of the vibratory cycle. These are the-rise time (relative duration of the rising flank), maximum and mean speed on the rising flank and the dip area which reflects irregularities in the rising flank.

This study concerns two kinds of measurements. We did reproducibility measurements and measurements over the chest register.

Reproducibility measurements were done with 3 healthy subjects, 2 males and 1 female, with good phonatory capacities. For every subject there were 2 sessions at different intensity and frequency levels with 8-10 phonations taking place shortly one after another.

The relations between the EGG parameters and the different qualities of voice were studied for 19 subjects, 7 normals and 12 pathologies. The population of normals consisted of 5 conservatory students (singers) and 2 subjects with untrained, unsteady voices. In the conservatory population there was 1 male subject (M.T.). For this subject we did 2 measurement sessions more than 1 month apart. The pathologies population had 3 males and 9 females and can be further subdivided into various classes of pathology. These measurements over the chest register were about 20 in number. The intensities and frequencies were taken with an attempt to cover the chest register evenly. The resulting EGG parameter values were averaged. Twenty measurements take about 0.5 h of measurement time and 3 h of processing time.

Processing of Measured Data

The processing of the raw EGG data is divided into three stages: (1) data reduction, (2) filtering and (3) averaging.

Data Reduction

A trace of 1.913 s of the EGG registration was sampled with 19,600 Hz (37,500 data points), during which time the intensity and frequency were kept constant as indicated before. Out of this trace an interval of 0.418 s (8,192 data points) starting at 0.26 s was selected. In figure 2 this time schedule is depicted.

At a phonation rate of 100 Hz the reduced data interval contains 41 periods. This data

reduction is done to get a suitable number of points with regard to the total processing time, filtering properties, computer memory and representativity of the complete raw signal.

Figure 2: The time schedule for data recording and reduction

Filtering

To obtain reliable averaging results it is essential to remove low- and high-frequency noise from the signal. Removal was obtained by Fourier filtering with cutoff frequencies of 5.5 and 4,000 Hz (forward transform window 10% split cosine, backward transform window rectangular). After the filtering procedure, 0.334 s (6,554 points) are left for further processing (33 periods at 100 Hz).

Averaging and EGG Parameters

After the filtering procedure the signal is averaged. The averaging procedure uses the differentiated signal to determine a trigger point per period. This differentiated signal contains sharp peaks at the upward slope of the EGG signal. When the noise of the signal is low enough, the upward slope peaks are the local maxima of the periods (fig. 3). The periods are superimposed to obtain an averaged typical period, using the trigger point as a reference.

ANALYSIS AND RESULTS

EGG Parameters Extracted from the Averaging Process

From the averaging process three parameters are extracted: the jitter, shimmer and the shape factor. The jitter factor is correlated with the horizontal (time) shifts, necessary to get the best superposition (fit) of periods using the least-squares criterion. This can be a measure for basic frequency (in)stability. The jitter factor for a sine wave, recorded from a signal generator (no attenuation; 1/3 of maximum output amplitude), can be as low as 0.6. As will be shown below, the mean value for a normal subject was found to be between 2 and 3.

The shape factor yields an indication about how good the average fit of the periods is.

It is directly related to the minimum sum of squared differences in amplitudes over the periods. For a sine wave the shape factor can be as low as 0.27. The shape factor depends on the noise level in the signal. High noise levels can arise from bad contact between the electrodes and the skin and because the voice in itself may produce a lot of noise. Generally shape factors go up to about 15. For pathological cases, shape factors were observed as high as 40.

The shimmer factor is a measure for the variations of the maximal amplitudes of the EGG periods. It is derived from the sum of squared differences between the maximum amplitudes of the periods and the averaged maximum amplitude over the periods.

EGG Parameters Extracted from the Averaged Signal

Seven parameters are extracted to characterize an averaged EGG period. The crest factor is the ratio between the peak value and the root mean square value of the averaged period. This ratio is normalized dividing by the crest factor of a single period of a sine, which has a value of 22.80. The crest factor reflects the peakedness (average width) of the EGG. In figure 3 the maximum and root mean square lines in the EGG are depicted.

Figure 3: One EGG period with its derivative. Some characteristic features are displayed: The absolute period time, rise time and closed time, the maximum and root mean square (RMS) values of the EGG and maximum differentiated value of the differentiated EGG (DEGG). T_{rise} = Absolute rise time; T_{closed} = absolute closed time; T_{period} = total period time.

The closed quotient is the time relative to the total period time that the differentiated data values lie in between the maximum and minimum (fig. 3). During this time span the folds have maximum contact at the maximum in the EGG, increasing contact on the rising slope and decreasing contact on the falling slope. We use the maximum and minimum speeds in the EGG as definition points for the beginning and end of the closed phase.

We define the speed quotient as the ratio of the maximum and minimum speeds in the EGG.

Rising Flank Parameters

The rising flank of the EGG is associated with the closing phase of the vocal fold movement. During the closing phase of this cycle, the folds move towards each other, and the conductance through the folds increases as does the electric current. If we assume the vocal folds to be homogeneous in conductivity, the changes in electric current reflect changes in contact area between the folds. Then the rising flank reflects those changes during the closing phase of the cycle. Properties of the rising flank such as the relative duration might be of significance with respect to the functionality of vocal fold closure. In figure 3 the rising flank is the part of the EGG curve between the dashed lines.

Figure 4: The dip area of the rising flank in the differentiated EGG. See also figure 3 for the rising flank. T_{rise} = Absolute rise time; t = time; the difference between the normal curve and the curve with dips is quantified by means of the sum of dip areas [$\sum: \text{dip}(i)$] divided by the total area.

The rise time is the relative duration of the rising flank to the total period time. The maximum and mean differences are the maximum respectively average diff's values of the rising flank after normalization of the EGG curve on both axes: in amplitude from 0 to 1 and in time by division by the period time (= number of points/sample frequency). See figure 3 for the absolute rise time and maximum differentiated value. The dip area is indicative of the irregularities in the rising flank as measured by the surface of dip areas in the differentiated EGG relative to the total enclosed area. In figure 4 the concept dip area is clarified.

MEASUREMENT RESULTS

Reproduction Measurements

To see how well the measurements with respect to the EGG parameters reproduced, we performed 8-10 measurements at fixed intensity and frequency for 3 healthy subjects (2 males, 1 female). For each subject there were 2 measurement sessions at different intensity/frequency pairs. The parameter values were calculated with their average values and SDs (standard deviations). In table 1 the results are summarized.

Table 1: Summary of reproduction measurements of 3 healthy subjects (average with SD), 2 males (R.B. and G.H.) and 1 female (L.B.)

sub	date	freq(Hz)	Int(dBa)	jitter	shimmer	shape factor	closed quot.	speed quot.
RB	061290	133-135	86-88	2.4 +- 0.2	-	1.8 +- 0.2	0.50 +- 0.02	4.0 +- 0.5
RB	071290	104-107	82-84	1.9 +- 0.1	1.0 +- 0.1	2.1 +- 0.2	0.43 +- 0.01	2.9 +- 0.3
GH	101290	136-138	77-79	3.2 +- 0.2	1.2 +- 0.1	2.1 +- 0.2	0.39 +- 0.01	2.9 +- 0.2
GH	101290	112-114	79-80	2.4 +- 0.2	1.6 +- 0.1	3.3 +- 0.2	0.42 +- 0.01	3.8 +- 0.3
LB	101290	228-229	77-79	3.9 +- 0.2	2.6 +- 1.1	13.4 +- 4.6	0.37 +- 0.03	2.9 +- 0.2
LB	101290	208-212	73-76	3.6 +- 0.2	2.8 +- 0.6	9.5 +- 3.2	0.34 +- 0.02	4.0 +- 0.4
sub	date	freq(Hz)	Int(dBa)	crest factor	rise time	max speed	mean speed	dip area
RB	061290	133-135	86-88	0.99 +- 0.01	0.06 +- 0.00	19.9 +- 0.9	15.2 +- 0.9	0.00 +- 0.00
RB	071290	104-107	82-84	1.05 +- 0.01	0.08 +- 0.01	15.9 +- 1.6	12.0 +- 1.3	0.00 +- 0.00
GH	101290	136-138	77-79	1.13 +- 0.01	0.08 +- 0.00	15.4 +- 0.5	12.5 +- 0.6	0.03 +- 0.01
GH	101290	112-114	79-80	1.06 +- 0.01	0.04 +- 0.00	26.6 +- 1.2	20.7 +- 1.3	0.00 +- 0.00
LB	101290	228-229	77-79	1.19 +- 0.05	0.12 +- 0.01	11.9 +- 0.8	9.1 +- 0.6	0.01 +- 0.00
LB	101290	208-212	73-76	1.23 +- 0.03	0.10 +- 0.01	15.7 +- 1.3	12.0 +- 1.2	0.00 +- 0.00

Measurements over the Chest Register

For a population of 15 female subjects we present the results of average values of the parameters over the chest register. A rough division has been made in the classes 'pathological' and 'normal'. The subjects phonated at several (around 20; exact number under n in table 2) different pairs of intensity and frequency within the chest register.

An attempt was made to cover the whole chest register evenly and reach the borders of this register especially.

In table 2 the measurement results are summarized. The results of the jitter, shimmer and speed quotient have been omitted as well as the results from the maximum speed. We deem that at the moment these parameters do not yield extra information compared to the displayed parameters. At a later stage they must be included when a more rigorous statistical treatment of more data is possible.

In figure 5 a graphical representation of the results in table 2 is given.

Table 2: Summary of measurement results from 15 female subjects

nr	subj.	n/p	age	nrs	diagnosis/remarks
1	JK	n	20	19	Conservatory student soprano
2	FW	n	20	29	Conservatory student alto
3	CB	n	22	23	Conservatory student alto
4	ACE	n	30	21	Conservatory student alto
5	AV	n	39	18	Unsteady, untrained voice
6	MB	n	51	10	Unsteady, untrained voice
7	CW	p	17	20	Nodules, breathy voice
8	ACO	p	18	19	Nodules, breathy voice
9	ES	p	21	21	Nodules, tensed voice
10	MA	p	23	27	Early nodules, post voice rest 8 days
11	JC	p	26	32	Glottal closure insufficiency
12	RS	p	26	17	Nodules, breathy voice
13	AO	p	33	17	Edema, weak voice
14	FS	p	51	10	Reinke's edema, post surgical (10 days), weak breathy voice
15	MS	p	53	17	Glottal closure insufficiency, no control of low intensities

nr	subj.	crest factor	closed quotient	shape factor	rise time	mean speed	dip area
1	JK	1.16 +- 0.02	0.36 +- 0.02	19.6 +- 4.0	0.11 +- 0.01	10.6 +- 0.9	0.03 +- 0.02
2	FW	1.11 +- 0.01	0.41 +- 0.02	15.0 +- 2.3	0.09 +- 0.01	12.5 +- 0.8	0.002 +- 0.001
3	CB	1.03 +- 0.01	0.48 +- 0.02	19.9 +- 2.2	0.12 +- 0.01	9.8 +- 0.7	0.03 +- 0.01
4	ACE	1.10 +- 0.01	0.37 +- 0.02	13.9 +- 1.9	0.09 +- 0.01	12.6 +- 1.0	0.02 +- 0.01
5	AV	1.06 +- 0.02	0.44 +- 0.03	26.5 +- 3.3	0.14 +- 0.01	8.3 +- 0.8	0.00 +- 0.00
6	MB	1.02 +- 0.01	0.45 +- 0.03	30.0 +- 2.7	0.15 +- 0.03	9.8 +- 0.7	0.03 +- 0.02
7	CW	1.03 +- 0.01	0.53 +- 0.01	32.3 +- 2.6	0.17 +- 0.01	6.5 +- 0.6	0.07 +- 0.03
8	ACO	1.06 +- 0.02	0.45 +- 0.01	12.7 +- 2.3	0.12 +- 0.02	8.3 +- 0.4	0.005 +- 0.003
9	ES	1.05 +- 0.01	0.56 +- 0.02	22.9 +- 2.9	0.14 +- 0.01	7.5 +- 0.5	0.06 +- 0.01
10	MA	1.05 +- 0.01	0.47 +- 0.02	33.4 +- 3.8	0.12 +- 0.01	9.1 +- 0.6	0.04 +- 0.02
11	JC	1.13 +- 0.02	0.36 +- 0.01	16.0 +- 3.1	0.13 +- 0.01	8.6 +- 0.4	0.00 +- 0.00
12	RS	1.17 +- 0.02	0.37 +- 0.02	19.0 +- 3.3	0.14 +- 0.01	7.7 +- 0.5	0.01 +- 0.00
13	AO	1.05 +- 0.02	0.52 +- 0.03	20.5 +- 6.0	0.16 +- 0.02	7.4 +- 0.9	0.07 +- 0.03
14	FS	1.17 +- 0.02	0.43 +- 0.03	17.2 +- 5.1	0.09 +- 0.01	10.8 +- 0.7	0.02 +- 0.01
15	MS	1.05 +- 0.02	0.52 +- 0.03	23.0 +- 3.6	0.11 +- 0.01	10.5 +- 1.1	0.07 +- 0.04

Figure 5: Results from averaging of EEG parameter values over measurements in the chest register. In this figure a graphical representation of the results in table 2 is given.

Crest factor

Rise time

Closed quotient

Mean speed

Shape factor

Dip area

CONCLUSIONS AND DISCUSSION

Reproduction Measurements

The reproduction measurements show us several things. Firstly, the parameter values are subject to a variation that compels the experimenter to do more than 1 measurement at the same frequency and intensity to get a reasonable estimate of the value. For instance, the SDs of the crest factor are within 5% of the values. The situation is worse for the shimmer and shape factors for subject L.B. Sds of the shimmer and shape factor are relatively much higher for L.B. compared to the values for R.B. and G.H. An SD of about 3.3 % of the value occurs for subject L.B. (13.4 ± 4.6). One should note that for instance in the case of the first rise time of subject L.B. (0.12 ± 0.1), the individual values varied from 0.09 to 0.15 (i.e. 0.11, 0.15, 0.09, 0.09, 0.13, 0.14, 0.10, 0.13; 8 measurements).

The measurements also show that some parameters are frequency and intensity dependent. This of course was to be expected because of the dependence of the EGG waveform shape on frequency and intensity [10]. Significant differences in the values of the crest factor as a function of the intensity and frequency can be seen. For subject R.B. the crest factor changes from 0.99 ± 0.01 to 1.05 ± 0.01 . Center intensities and frequencies were 87 dB (A), 134 Hz and 83 dB (A), 105.5 Hz, respectively. Also the rise time can vary significantly, e.g. for subject G.H. from 0.08 - 0.00 to 0.04 - 0.00.

A lot of noise in the signal will influence the shape factor negatively, i.e. raise the value of the shape factor. One should realize that noise can originate from the measurement equipment but the voice as well.

Assuming that the noise level is constant, a low signal-to-noise level is a consequence of a low signal amplitude. This signal amplitude varies from subject to subject as the maximum differences in electrical conductivity (the quantity that is being measured) change from subject to subject. Also, the direct current resistance of the conducting tissue between the electrodes of the laryngograph can be so high as to diminish the measurable effects of a changing resistance of the vocal folds. In other words: the signal amplitude decreases as the direct current resistance of the conducting tissue reaches a critical (high) value.

The noise level can be increased as a consequence of bad voice quality itself. A hoarse or breathy voice does not only sound noisy but can be hypothesized to generate noise in the EGG signal. Noisy sounds could be caused by vocal folds vibrating at high frequency (noise) levels superimposed on the normal vibration without noise.

The results indicate that intensity and frequency are not the only parameters that influence the EGG parameter values. Having kept these fairly constant [within 1-3 dB (A), 1-4 Hz] the variations in the EGG parameter values are significantly higher (by percentage). As reported in the literature [8] the source (lungs + vocal folds) is influenced by the tract (pharynx cavity + nasal cavity + oral cavity). Vowels corresponding with different positions of the articulators influence the mode of vibration of the vocal folds. An [a] phonated at a certain intensity and frequency yields another EGG waveform than an [i] phonated at the same levels. In the same way it is possible to pronounce

ce an [a] in different ways (open, closed, constricted), giving rise to variations in the mode of vibration of the folds and thus in the EGG.

Also, at the level of the source (vocal folds) there are variations possible. A vowel can for instance be pronounced with more or less air. The [a] will become more of a [ha] with more aspirated air. The average position of the folds will be more open, and the EGG wave is certainly expected to be different. All these alterations permit an extraordinary diversity in phonations [7]. We determined the EGG only as a function of intensity and frequency. The determination of other factors that influence the EGG could not be realized in the present setup.

It is most important to get control over the other factors that influence the EGG waveform to improve the reproduction of the measurements. As is made clear above, the resonance in the mouth and nasal cavities (position of the articulators) and the amount of air flowing through the glottis probably play an important role in the EGG registration. A possible feedback for the subjects might be a frequency spectrum of the acoustical signal. This spectrum should be kept as constant as possible.

A point of interest for further study must be the variations in EGG parameter values within one phonation. In view of the discussion above they are possibly small compared to the variations from one measurement to another. We have indications that this is in fact the case.

Measurements over the Chest Register

About 20 measurements were taken over the chest register, and the resulting EGG parameter values were averaged. The results of the reproduction measurements show that a number of measurements per intensity and frequency are needed to get a reasonable estimate of the EGG parameter values. The parameter values vary over the chest register. The average of a number of measurements over this register is strongly dependent on the position of the measurement points. The determination of sets of points that are comparable from subject to subject is therefore one of the problems we are confronted with. Each individual has a different chest register with regard to size and position. It is obvious that one cannot use a common set of points. There are indications that measurements at the borders of the register enlarge intersubject differences. The ideal situation would be of measurements over the entire register (with a certain resolution) as is done by Pabon and Plomp [12] for the acoustical signal. At the moment this is not possible with our soft- and hardware.

Another aspect that must not be overlooked is the choice of the parameters. We have opted for a pragmatic approach in our choice of parameters. Starting out with visual inspection of the signals we chose parameters we believed to yield discriminative information on inter- and intrasubject functioning, at the intrasubject level as a function of time, intensity and frequency. As a function of time one should think of differences over time as depending on the physical well-being of the vocal folds. For instance after a period of strain (e.g. loud speaking) the EGG waveform might be altered, and the parameters should reflect this vocal load.

At the intersubject level one should be able to discriminate on the basis of average

values. It is clear that the choice of parameters plays a very important role in this as well as the averaging procedure. The choice and definition (calculation techniques) of the parameters must be subject to refinements. For instance, we have not yet investigated the downward slope of the EGG wave.

Before we start discussing the measurement results in more detail, we must make a few remarks with regard to the interpretation of the results. The values of the EGG parameters have been graphically displayed on a linear scale in figure 5. Comparison of these values is not done beforehand best on a linear scale of course. Maybe for some parameters for instance a logarithmic scale is better. Having no criteria for this we cannot offer a solution to this problem at the moment, and the reader has to content himself with the present presentation.

It must also be emphasized that, although we divided the subjects into the groups of normal and pathological voices, it certainly cannot be expected that on the basis of the EGG parameters one can discriminate between these groups as a whole. The reader must realize that under the definition of pathological a whole spectrum of different vocal fold disorders lies. In this study we have seen several examples of these such as nodules, edema or unilateral paralysis. Also in the group of normals there will be many different 'blood groups'. One can for instance make a rough subdivision between trained supervoices (conservatory students) and untrained normal voices (persons without complaints). Research in characterization of the EGG parameters in more specified groups will be done in future.

As the number of subjects in this study is limited and the number of potential categories to divide them in is large, a statistical treatment of the data is not possible. This means that it is dangerous to make any comments on the results because there is no statistical evidence. For further study it is recommended that a great number of measurements be done to overcome this problem.

For all parameters there is a large variation over the subjects. A division into certain categories on the basis of these results is not possible. This is especially the case for the crest factor and the closed quotient.

The closed quotient was thought to give an indication of the relative time when the vocal folds are closed. The criterion used is that of maximum and minimum speeds on the rising and falling flanks. Another parameter that might give more information on the amount of relative closure is the relative surface area under the EGG curve compared to the area of the rectangle that encloses the curve.

The shape factor results show a great variation, which makes it difficult to interpret. Measurements not reported here yielded values as low as 1.8 and 2.7. Of these values one can be sure that there was low signal noise on the level of the subject performance (intrinsic noise) as well as on the extrinsic level (system noise, electrode-skin contact). For higher values it can normally not be determined what the noise source was (intrinsic/extrinsic). Other measurements also showed that, while other parameter values remained constant over two different sets of measurements, the shape factor could vary a lot (i.e. 300%).

One should bear in mind that a lower signal-to-noise ratio leads to a higher shape

factor. This could also lead to a higher rise time because the periods will be more shifted to get an optimal overlap in the averaging process. More noise in the signal can cause rising flanks not to overlap optimally.

The group of female conservatory students (No. 1-3) seems to score low on rise time compared to the other female normals (No. 5 and 6) but also to the pathologies. This does not extend over the whole range. For the mean speed the situation is reversed with respect to the rise time. The rise time and mean speed have an inverse correlation: the higher the mean speed, the shorter the rise time. The rise time gives an indication of the duration of closure of the vocal folds.

The use of EGG parameters to determine the functioning of the vocal folds is not in a stage that one can make a division into types of vocal fold functioning on the basis of these parameters. The arsenal of parameters might be enriched with more, and the determination of some of them might be modified. The phonation conditions have to be stricter to improve reproducibility. Not only the intensity and frequency have to be kept constant but also other parameters such as position of the articulators and the air flow through the glottis.

To obtain an objective judgement on voice quality, the authors prefer the use of EGG parameters to a classification on the basis of the EGG waveform as is done by Motta et al. [11]. The approach of Pabon and Plomp [12], i.e. using quality parameters of the acoustical signal by doing measurements over the entire voice field with a resolution of 1 semitone and 1 dB, is one we also recommend for EGG parameters. The current situation does not allow for this as hardware is concerned.

A further problem is the absence of standard values for the EGG parameters with which to compare the results. Also the choice of scales on which to compare the results must be an item of discussion. It is certainly not proven that a linear scale is best for all parameters. Still, the method offers possibilities for further research not in the least because it is easily widely applicable.

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Chapter

5

**Are voice endurance tests able to assess
vocal fatigue?**

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ABSTRACT

Voice endurance tests are often used to evaluate voice fatigue or to test the suitability of an individual for voice demands. It is assumed that these tests help to identify subjects with laryngeal or vocal fatigue out of a population of persons with complaints of discomfort in the throat, recurrent hoarseness and decreased voice power.

In this study we evaluated the Voice Interval Test with respect to its discriminative power by comparison of voice performances in 20 patients with a history of vocal fatigue with that in 12 healthy subjects. Voice performance was studied during the Voice Interval Test as well as during regular use of the voice on a working day by electroglottography, acoustic analysis and a self-rating scale for pain and fatigue. Despite the number of tests the data did not reveal any significant difference between the patients and the healthy subjects.

Vocal fatigue could therefore not be identified and the clinical relevance of the Voice Interval Test appears to be questionable.

INTRODUCTION

Voice complaints induced by professional demands are not a frequent problem in occupational medicine [1,2] but are underestimated [3] by physicians and patients. Many professions depend on voice performance which is only acknowledged if one starts to suffer from voice complaints. Symptoms induced by voice fatigue are not often recognised as first signs of impairment. Only in a limited number of subjects does it appear to be possible to explain the symptoms on the basis of the observed organic abnormalities. In many cases no morphological or physiological defects are found, despite severe complaints. However, slight swelling or impaired closure of the vocal folds and fatigue of the laryngeal muscles often results in a hoarse or less sonorous voice. As a consequence some authors suggest that acoustic analysis is a very sensitive method to reveal these abnormalities and that they become audible even before they become visible [19, 5]. In contrast others claim that in some cases, oedema and hyperaemia of the vocal folds are visible while the voice still sounds normal and clear [6,7]. As visual inspection of the larynx does not provide exclusive information about the impact of voice endurance [8-11], there is considerable need to investigate and measure voice fatigue by a well defined endurance test. At present, there is no standard method to evaluate the effect of voice endurance upon voice performance. The so called Voice Endurance Test recommended by the Union of European Phoniaticians [4] has not been validated with objective measurements yet and so far, prediction of professional voice capacity by use of equivalent tests that objectify the impact of voice endurance upon voice performance appears to be poor [6, 13-21] partly be explained by an inappropriate choice of parameters to measure voice fatigue, or by the possibility that the endurance tests applied might not be rigorous enough to induce substantial vocal fatigue. Moreover, extrapolation of the test results into the working situation might also be limited. It is evident that the laboratory test conditions often differ markedly from the real working situation where environmental factors like humidity and dust beside individual factors like stress and communicative interaction play an important role in voice performance.

To gain greater insight into the impact of voice endurance, patients with voice complaints were compared to a control group of healthy volunteers without any symptoms of voice fatigue. Electroglottography (EGG), acoustic analysis and a self-rating scale for pain and fatigue were used to monitor vocal fatigue. EGG was used to quantify vocal fold closure. It was hypothesised that:

1. the closure rate would be slower in the patients than in the control group;
2. vocal fold contact would decrease as the test became more difficult.

We also investigated whether changes in objective voice parameters as revealed by the Voice Interval Test could be related to voice performance in working day activities.

The results of the above-mentioned investigations were linked to the self-rating scale, on which the participants scored pain, fatigue, discomfort or globus sensation in the throat on a visual analogue scale. To evaluate the validity of the Voice Interval Test,

measurements were performed on all the participants before and after a normal working day.

SUBJECTS AND METHODS

The patient group was selected from women registered at our phoniatric outpatient clinic who met the following inclusion criteria: age between 20 and 50 years and a history compatible with vocal fatigue; laryngostroboscopy revealed dorsal glottic insufficiency, vocal nodules, anterior thickening, spindle-shaped incomplete closure or hourglass-shaped closure of glottal folds, (border) oedema. Any patients with other disorders, such as thyroid abnormalities, chronic obstructive pulmonary disease or patients with medication which could interact with voice performance, were excluded. The patient group selected in this way comprised 20 women with an average age of 26 years ($SD=5$).

The control group was selected from healthy women with a normal voice, aged between 20 and 50 years who had no history of voice complaints or disorders and had a profession or hobby that implied frequent voice use. The control group comprised 12 women with an average age of 28 years ($SD=3$). The patient and control groups were matched with respect to smoking, alcohol use, and eating habits. A written informed consent was obtained from all subjects at enrollment.

EKG recordings and analyses

The EKG signal of each participant was measured before and after the Voice Interval Test and before and after work. The signals were recorded from a Fourcinq laryngograph. Electrodes were placed on either side of the neck, directly over the thyroid alae. Computer analysis was performed via a special module of the Computerised Speech Lab from Kay Elemetrics. This provides a real-time extraction and display of the EKG waveform and quotients. In this way, two parameters were measured that are of importance for determining vocal fold movements: the jitter quotient, which reflects the level of irregularity in the EKG waveform signal and the contact quotient, which determines the degree of contact/closure of the vocal folds.

The participants were asked to phonate an [a] at their normal intensity (65-70 dB) (220 Hz) and a loud [a] (75-80 dB) at 330 Hz.

Acoustic recordings and analysis

Acoustic signals were obtained by asking the participants to phonate a prolonged [a] in front of a microphone (30 cm from the mouth) at their normal and most comfortable frequency and loudness. The time course, frequency and intensity of the signals produced by the subjects were displayed real time on a monitor to provide visual feedback. This feature allowed the subjects to reproduce signals on request at the various measuring sessions. A phonation of 3 seconds duration was necessary to allow an accurate spectral analysis with use of the Multi-Dimensional Voice Program (Table 1).

Table 1: The Multi-Dimensional Voice Program is a clinical assessment with graphical and numerical analysis of a sustained phonation. The program compares the extracted parameters with a built-in database.

RAP:	Relative Average Perturbation gives an evaluation of the variability in the pitch period within the analysed voice sample at smoothing factor 3 periods.
PPQ:	Pitch period Perturbation Quotient gives an evaluation of the variability in the pitch period within the analysed voice sample at smoothing factor 5 periods.
SHDB:	Shimmer in dB gives an evaluation of the period-to-period variability in the peak-to-peak amplitude within the analysed voice sample.
sAPQ:	smoothed Amplitude Perturbation Quotient gives an evaluation of the short or long term variability in the peak-to-peak amplitude within the analysed voice sample. The sAPQ smoothing factory setup is 55.
NHR:	The Noise-to-Harmonic Ratio contrasts the periodic or regular signal produced by the vocal folds with the "noise" or aperiodic signal from the vocal folds and vocal tract. The more hoarse or "noisy" a voice is, the lower the NHR. A high NHR indicates a clear voice.

Pitch and loudness were recorded continuously during the Voice Interval Test. As acoustic effects have also been described in terms of a decrease in power and volume²² or as increases in the fundamental frequency of speaking^{6 21 23}, these aspects were also evaluated during the test. In 3 patients and 3 controls, a voice accumulator²⁴ was used to monitor loudness during the measurement day and during 2 other working days.

Self-rating of pain and fatigue

Complaints were categorised by the use of a visual analogue scale on which the participants scored the degree of voice fatigue, pain, dry/burning feeling and globus sensation in the throat. Complaints were evaluated during four measuring sessions: before and after the working day, and before and after the Voice Interval Test.

The Voice Interval Test

The participants were instructed how to use their voice precisely. The assignments were incorporated into the text of a play-scene which was used as a basis for the endur-

ance test. Various voice fatiguing tasks were implemented such as: read the next page as loudly as possible; read the next page at a whisper; read the next page with a low, creaky voice; make a number of noises (a siren, bark like a dog, bray like a donkey, snore, etc.), sing *Frère Jacques* three times at a different pitch; cough three times; read the next page in a child's voice, etc. Every test lasted for five minutes and was repeated six times (30 minutes of endurance in total). Compared with the voice use of a working day this test has a short duration with longer periods of speaking loudly and it is calculated that this produces a comparable vocal load. To motivate the subjects and to promote substantial voice load, all participants were told beforehand that they would receive a fee that increased with the phonation intensity amplitude and intensity range that they were able to produce.

Statistical Analysis

Statistical analysis was made by a multivariate analysis of variance, and non-parametric tests (Wilcoxon and Mann-Whitney) using SPSS version 7.5 (SPSS, Inc).

Measurement procedure

Pitch and loudness were measured after each 5 minutes test, so six times in total per session.

Additionally, EGG, acoustic analysis and self rating were registered before and after the Voice Interval Test and working day. To compare the vocal load during the Voice Interval Test to that of a working day, each participant was measured on two different days: on one day the test was performed and on the second day the working day measurements were taken. Generally, the test was performed 2 or 3 days after the work exposure accumulation. In some cases the test was performed before the working day measurements, which implied that the interval between the two measurements exceeded one week. The test performance was preferably timed in the morning. Vocal load of the working day was quoted by the subjects as lower, equal or more intense than normal use; in 6 patients this was also monitored with use of a voice accumulator.

RESULTS

EGG analyses

In 8 patients, the EGG signals could not be analysed because they were too weak and irregular, and not reproducible. In the remaining 12 patients, there was no significant difference between the EGG values obtained before and after the working day ($p < 0.05$). In contrast, the contact rate of the vocal folds at 220 Hz phonation was significantly lower after the Voice Interval Test than before. All other parameters obtained by EGG were not significantly affected by the test.

All EGG signals in the control group could be analysed. The EGG values obtained before and after the working day were not significantly different ($p < 0.05$). After the Voice Interval Test, the contact rate of the vocal folds at 220 Hz phonation was again

significantly lower than before ($p < 0.05$). All other EGG parameters were not significantly affected by the test. Multivariate analysis of variance (Manova) confirmed that the voice endurance did not affect the EGG parameters, apart from a significant decrease of the contact rate ($p < 0.05$).

Acoustic characteristics

In neither the patients nor the healthy subjects did the acoustic values RAP, PPQ, SHDB, APQ and NHR change before and after the working day or Voice Interval Test ($p < 0.05$). Similarly, no significant different acoustic characteristics as revealed by the spectral analysis were observed between patients and controls.

During the Voice Interval Test, the same text was read as loud as possible at 5-min. intervals and the pitch and loudness were measured. The results are shown in figs. 1 and 2. Pitch and loudness did not differ between patients and the controls. A slight (however statistically not significant) increase of both pitch and loudness with successive 5 min. interval in the control group was observed. Similarly a slight statistically not significant increase of loudness was observed in the patient group. There was no significant difference between pitch and loudness between patients and controls either.

Figure 1: Average loudness of loud speech measured at 5-minute intervals. There was no significant difference in volume between the two groups and no loss of power

Figure 2: Average pitch of loud speech measured at 5-minute intervals. There was no significant difference in pitch between the two groups and no increase of pitch.

Self-rating of pain and fatigue

Pain, fatigue, discomfort in the throat (dryness, burning) and globus sensation, were evaluated by a self rating visual analogue scale. In the patient group, no significant differences between the scores for any of the parameters before and after the working day were observed. However, after the Voice Interval Test, the patients did report significantly more fatigue, pain and discomfort in the throat than before the test ($p < 0.01$).

In the control group, only fatigue increased significantly after the working day. Fatigue, pain and discomfort in the throat also increased significantly after the Voice Interval Test.

When the two groups were compared, only fatigue after the Voice Interval Test increased significantly more in patients than in controls ($p < 0.05$). All other parameters did not differ significantly between the two groups.

Table 2: Comparison of the self-rating scores before and after the Voice Interval Test and the working day.

nonparametric tests single-sided p-values		Wilcoxon			Mann-Whitney U
		controls	patients	both	patients versus controls
fatigue	work	0.02	0.23	0.03	[0.19]
	VIT	0.04	0.01	0.002	0.03
pain	work	0.21	[0.30]	[0.47]	[0.29]
	VIT	0.01	0.01	0.001	0.21
discomfort	work	[0.23]	0.37	[0.24]	0.34
	VIT	0.01	0.01	0.001	[0.37]
globus	work	[0.50]	[0.30]	[0.46]	[0.40]
	VIT	0.33	[0.17]	0.12	[0.07]

Table 3: Comparison of the self-rating scores between the working day and the Voice Interval Test.

nonparametric tests double-sided p-values	Wilcoxon		
	controls	patients	both
fatigue	0.4164	0.0747	0.2662
pain	0.0458	0.0277	0.0029
discomfort	0.0464	0.0277	0.0029
globus	1.0000	0.9165	0.6353

DISCUSSION AND CONCLUSIONS

Analysis of the **EGG** results did not show any evidence of vocal fatigue in either group. It is possible that EGG is not sensitive enough to detect changes caused by vocal use during a working day or the Voice Interval Test. Another explanation could be that the working day and the test did not cause any changes in vocal fold contact. The latter explanation seems to be in contrast to the impact of vocal load upon some complaints (see below).

The similarities between the EGG results on Voice Interval Test and working day do not allow the provisional conclusion that the test is a reasonable reflection of vocal fold function during a working day.

The significantly poorer vocal fold contact rate at 220 Hz after the test in both the patients and controls of course needs confirmation by other measurements. However our consistent findings support the results of Linville²⁵ who stated that changes in glottal configuration after loud talking show interspeaker variability and that laryngeal adjustments are more affected by changes in pitch than by changes in loudness. However, it remains to be seen whether the apparent increase in glottal closure persists for any length of time in loud talking and whether it might indicate whether an individual has a tendency towards developing vocal hyperfunction.

No significant differences could be observed regarding the **acoustic** parameters. Two possible conclusions can be drawn from this: the equipment / parameters were not sensitive enough to measure possible acoustic changes, or no acoustic perturbations have occurred. The patient group was able to produce speaking volumes of 85 dB and even were able to do so after 20, 25 and 30 minutes; we had expected a gradual decrease in both groups and a relatively larger one in the patients. This finding again supports the idea that the voice endurance might not be sufficiently arduous to induce pronounced changes.

Concerning speaking fundamental frequency, only the range of pitch levels was wider in the patient group. The fact that the voice did not deteriorate more after the test than after the working day is very fortunate, because the participants (and other subjects) judged the test to induce considerable strain. The Voice Interval Test appears to provide more subjective stress but objectively this is not confirmed and it remains to be seen if the test is a representative reflection of vocal load during a working day.

The **self-evaluation** of fatigue showed a significant increase in the control group after the working day, which did not hold for the patient group. This finding might be explained by the fact that the controls now were focused on their voice and the patients spared their voice during the working day. A large number of patients mentioned that as a consequence of their complaints, they had started to talk less or had been incorporated in more suitable work. The control measurement with a voice accumulator did not reveal any differences in voice use between the measurement day and the two other randomly chosen working days. The vocal stress of the measured working day is

representative and there are no indications for less or more fatiguing activities. It was not possible to compare the patients' present voice use to their previous performance, because no measurements had been obtained before the onset of complaints. After the Voice Interval Test, both groups of participants had significantly higher scores for the parameters fatigue, pain and discomfort in the throat than before the test. We can conclude from this that the test was more of a strain than the working day. However, it should be mentioned that all the participants, but especially the patients, had expected that the test would be able to demonstrate abnormalities in their voice. Nevertheless for the time being, their subjective voice fatigue cannot be assessed by EGG or acoustic analysis.

When asked to evaluate the condition of a person's voice, it seems important to take fatigue factors and personality factors (such as mental strength, reduced motivation, reduced activity, stress coping style and self-esteem) into consideration. Past events and future expectations are probably more important than actual performance²⁶.

A laboratory setting (Voice Interval Test and other voice endurance tests) with a short and sharp voice strain are not the same as the natural setting. At present, vocal endurance can be monitored and recorded outside laboratory conditions by modern equipment, such as a voice accumulator, digital audio tape recorder and a lap-top computer. This can take place in a natural context that influences behaviour or voice and cannot be created in voice laboratories.

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Chapter

6

**Impact of phonation intensity upon pitch during
speaking:
a quantitative study in normal subjects**

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ABSTRACT

During speaking pitch level varies with phonation intensity. However the exact relation is unclear. It is not fully understood whether this relationship has any prognostic value towards voice disorders. To gain more insight in these aspects voice fundamental frequency was measured in 250 normal subjects without a history of voice complaints or treatment. Subjects were asked to produce tokens of speech at five different levels of loudness. Compared to women, men commanded a greater dynamic range. Pitch appeared to rise exponentially with phonation intensity. This non-linear relationship appears to be equal in male and female speakers. Detection and quantification of pitch rise with increasing loudness during speech appeared to be easy and might contribute to gain insight in aspects of voice capacity and quality.

INTRODUCTION

Voice capacity can be expressed in terms of the ability to speak at low and high intensities as well as at low and high frequencies. Voice pedagogy and voice control might be considered in terms of the ability to master fundamental frequency and volume independently and voluntarily. To evaluate both, the first might be accurately assessed through a classical phonetogram, whereas the latter might require the quantification of the relation between pitch and loudness. Results of several studies indicate that increase in loudness of the voice is accompanied with increasing frequency [20, 35, 21, 9, 29, 17, 11, 22, 12, 13, 10, 5]. In his experiments concerning the influence of masking by noise upon speech, Dieroff [9] observed tone shifts of a third in 8 subjects and no pitch change in 2 subjects. Tarnaud [35] and Lane and Travel [19] point to a high variability concerning this pitch rise. Remarkably, in his study titled "Der Lombardsche Versuch in dB und Hz gemessen", Yannoulis [38] does not discuss the pitch rise he observed at all. Lafon [18] considered any observed pitch increase as "deviant", although it was observed in many normal subjects. Apparently involuntary pitch rise is misjudged frequently: it is either neglected or regarded simply as deviant.

More recently, the relationship between changes in voice pitch and loudness is investigated more precisely. Gramming et al. [12] analysed these changes in patients with vocal dysfunction (white noise at 70 dB SPL in the earphones) as well as in professional singers and nonsingers without voice complaints (low-pass filtered masking noise). All the subjects read a discursive text with and without the masking noise at three loudness conditions. Grossly, mean pitch was found to increase by about half-semitones per decibel soundlevel in all the subject groups, although the singers changed voice pitch more than the nonsingers.

In this study we collected normative data of, and analysed in detail the relationship between loudness and pitch during speech in normal subjects without voice complaints.

SUBJECTS, MATERIAL AND METHODS

Subjects

250 subjects, 125 females (age range 15 - 65, mean age: 27, SD = 10) and 125 males (age range 18 - 67, mean age: 31, SD = 12) without voice complaints, never treated through voice therapy or phonosurgery, volunteered for this study.

Measurement equipment

Fundamental frequency (F0, pitch, semitone) was determined with a special electronic device, the Korg Autochromatic Tuner AT-12. This system covers a full seven octave range from 32 Hz to 3.9 kHz to allow accurate tuning of any voice. Solberg [33] showed that the measurements of connected speech samples with this portable fast-

tuning instrument correlated very highly ($r = .99$; $p < .0001$) with those made by the Visi-Pitch. The interjudge (.97) and intrajudge (.98) measurement reliability indicated that measurements made with this tuner can be made reliably

Phonation intensity (dBA, volume, loudness) was detected by a Quest Sound Level Meter Model 2400 equipped with a prepolarized (electret) microphone Model EM-23 . The LCD display provides a numeric readout of sound level in 1 dB increments every second. The overall mean of each sample was obtained by the LEQ function of the micro-kit. For frequency weighting characteristics the dBA mode was selected. For electronic stability and sensitivity we used the low range switch (30-100 dBA). In only a few maximal volumes of 100-110 dBA we switched on the high range (70-140 dBA). All measurements were performed conformably to the recommendations by the Union of European Phoniaticians [30]: registrations were obtained in a room with normal acoustics and dimensions of minimal 4 x 4 x 2.7 m in order to keep reverberations to a minimum, and the microphone was placed at a fixed distance of 30 cm from the mouth.

Procedure/Instructions

First, the Speaking Fundamental Frequency (SFF) and intensity of habitual speaking was measured during conversation but also by serial counting as 29, 28, 27... because counting has a smaller F0 range and confirms the mean frequency of relaxed speaking (modal F0 of a reading passage is slightly higher than the mean for speaking. [2, 13, 1].

Second, the Fundamental Frequency Range (FFR) is determined. First the lowest fundamental frequency (mintone) is determined by pitch lowering downwards from SFF. Then the highest fundamental frequency (maxtone) is detected by pitch rise starting again from SFF. The thus obtained FFR is then verified by gliding from the highest to the lowest frequency and vice versa.

Third, the Intensity Range of Speaking (IRS) is measured. The subjects do not receive any instruction to keep tuned in order to detect the "natural " pitch rise as a function of phonation intensity. Subjects are requested to count at five levels of loudness in the following order:

- at a comfortable conversation level (volume 2)
- with raising voice (volume 3)
- with an even higher level of raising voice (volume 4)
- as loud as possible (volume 5)
- as soft as possible (volume 1)

During this procedure pitch was determined as a function of speech intensity.

Data analysis

Pitch levels were expressed according to the numerical classification of semitones from Vennard (1967): $G = 31, c = 36, a' = 57...$ adapted from the SemiTone Scale (STS) of The Acoustical Society of America (ASA)

Data were stored in a database (Fox Base). An analysis of variance (ANOVA) was

executed with use of SPSS-PC version 6.0 (SPSS Inc, Chicago, USA).

Results

Normal speech requires variation in fundamental frequency and the pitch sigma of counting appeared to be smaller. We observed a range of two semitones (males = ST 32-34, 104Hz - 116Hz and females = ST 41-43, 174 Hz - 196 Hz) during counting at comfortable conversation level Volume 2. During reading or conversation this range increases by three semitones (males = ST 32-37, 104 Hz - 138 Hz and females = ST 41-46, 174 Hz - 233 Hz). Upon increasing the volume of speaking the maximum rise in pitch was about one octave in both males and females.

The average lowest tone in men was ST 27 (SD = 3) or 78 Hz and ST 36 (SD = 2) or 130 Hz in women. The average highest tone was ST 59 (SD = 6) or 493 Hz in men and ST 66 (SD = 8) or 740 Hz in women. The variation in the mintone is smaller than that in maxtone. The range in fundamental frequency is 29 semitones (SD = 8) in females and 31 semitones (SD = 7) in males; the mean maximum phonational frequency range of this group is 2,5 octave..

The maximum speaking volume was found greater for males (94 dBA, SD = 6) than for females (89 dBA, SD = 5). The Intensity Range of Speaking appeared to be greater in men than in women (36 dB versus 31 dB). As a consequence the relative pitch range was greater in females than in males.

The average pitch rise observed at 5 speaking levels is depicted in Figure 1. It must be stressed that -despite displayed at the same position on the abscissa- the absolute values of the five volume levels differ from subject to subject and between men and women.

Tone 1 is 5 semitones above mintone in both sexes. Tone 5 increases about one octave in both males and females (resp. ST 32 to ST 45 and ST 41 to ST 53). When comparing male and female speakers there consists a distance in F0 of about 9 semitones.

Figure 1: Normal subjects: • Females ◇ Males. Average speaking fundamental frequency (semitones) of the five intensity levels.

The average volume 1 in the total group of subjects is 58 dBA (SD = 5). The average volume 2 is 69 dBA (SD = 5). There is no significant difference between volume 1 and volume 2 in speech of men and women (see Fig. 2). In contrast, volume 5 is significantly different when comparing male and female voices ($P = 0.01$): on average men can produce running speech at 94 dBA (SD = 6), women reach 89 dBA (SD = 6) maximum.

The Intensity Range of Speaking is significantly different between males and females : 36 dBA (SD = 8) and 32 dBA (SD = 6) respectively ($P = .005$). It is demonstrated that healthy voices cover a range of 30 dB and more for speech communication.

Figure 2: Normal subjects: • Females ◊ Males. Average speaking volumes (dBA) of the five intensity levels.

Figure 3 displays in more detail the relation between louder speaking and pitch rise (averaged over men and women because there is no difference). In order to obtain the result depicted in figure 3, the data were processed as follows. First, pitch rise was plotted against speaking sound level for each subject. Second, these individual data were fitted with a straight line using a least square algorithm. Thirdly, the individual pitch rise induced by an increase of loudness of 10, 20, and 30 dB was calculated based upon this linear fit through the data points. Ultimately these calculated individual pitch rises were averaged to process figure 3. Only 118 men (94%) and 99 women (79%) could increase speaking intensity by 30 dB or more. All subjects could increase speaking intensity by 27 dB or less. The averaged pitch rise upon a volume increase of 30 dB is 9 semitones (SD = 3).

The data points are best fitted by an exponential curve, which illustrates that the pitch rise varies not only on the increase of loudness but also upon the absolute speaking

volume. (See Fig. 4)

As a consequence in the first 10 dB interval a rise of 2 semitones (SD = 1), in the second 10 dB interval a rise of 3 semitones (SD = 1) and in the third 10 dB interval a rise of 4 semitones (SD = 1) is observed. No significant differences were observed with respect to pitch rise, when comparing men and women.

Figure 3: Exponential rise in semitones (ST) when increasing the volume of speaking 250 normal subjects, no difference between men and women.

Figure 4: Normal subjects: • Females $\diamond$ Males. Rise in semitones while speaking louder in shifts of 10 dB. F_0 pitch rise depends on the absolute speaking sound level.

DISCUSSION

Vocal performance and voice quality are quantified more and more by use of phonetography and acoustic analysis respectively; in general these voice function tests are performed under laboratory conditions. However, several quality aspects of the speaking voice, essential in daily life, could be underrated when evaluation occurs under laboratory conditions only. This might account for the incongruences between outcome of these function tests and subjective judgement of daily life (voice) performance and quality [6, 27, 15, 32]

Quantification of the phonetographic range does inform us about voice capacity in general and thus of the speaking voice too [31]. Brunner [5] stated that detection of the phonetogram should be a standard procedure in the diagnosis of voice disorders. She determined frequency and intensity at different vocal efforts like normal speaking, speaking loudly till crying and singing. However, the speaking voice uses only a small extent to the total voice field, despite the strong impact on human communication and function: Hacki [13] located the speaking voice area in the lower third of the phonetogram of the singing voice. Additionally, there are typical differences between singing and speaking: singing requires an independent control of pitch and loudness, while in speech, loudness and pitch can be related. Singers need to produce the same tone at different sound levels (decrescendo-crescendo), while during natural speech an increment in loudness seems to be typically associated with a rise in fundamental frequency [34]. Specific objectivation of the spoken voice capacity might therefore yield other results in singers or trained voices. Voice measurements of speech performances perhaps manifest more relevant characteristics than a quantitative evaluation of the voice in general.

Several studies indeed focused onto quantification of the speaking voice. Gramming et al. [12] investigated the relation between pitch and loudness and found an increase of about 0,4 semitones (ST) per decibel (= 12 ST/30 dB). In general, the results of our detailed study in normal untrained subjects confirm this relationship, either only 9 ST/30 dB, but we observed a different pitch rise at loud and loudest speaking intensities. In the intensity interval between 60 and 70 dBA pitch rise is smaller (0.19 in females, 0.20 in males) than between 80 and 90 dBA (0.55 in females, in 0.52 males). Fig. 5 visualizes the voice characteristics in terms of the rise in semitones as a function of increase in loudness (for practise in subjects with a lower or higher conversation semitone, the pattern can be slipped to her/his speaking F0).

Figure 5: Pitch rise in speaking while increasing 10, 20 and 30 dBA, implemented in the phonetogram chart.

The accompanying rise in fundamental frequency with louder speech might be related to the effort of the laryngeal muscles in glottic closure and subglottal pressure. An increase of speaking intensity requires an increase of subglottal pressure, and -on the average- a 1 cm H₂O rise in subglottal pressure is known to result in an increase of the fundamental frequency with 4 Hz [34]. Efficient loud speaking requires glottic closure without strain or constriction and precise respiratory muscle activity. An inefficient sound pressure level control and inappropriate laryngeal muscle effort results in wrong speech respiratory behaviour and compensating muscle activities[24, 3], but also in pitch elevation [26]. To explore the possible relation between pitch rise, laryngeal muscle function, speaking voice quality and vocal performance, we are now studying the involuntary pitch rise in subjects with weak (minor) and strong (major) voices, in patients with voice complaints, patients before and after therapy etc. In a pilot study we observed an increased involuntary pitch rise in 20 subjects with voice complaints and vocal fatigue out of 50 female teachers [4]. Literature mentions different and contradictory results, justifying further research[16, 37, 29, 12, 11].

Concerning speaking F0 we observed lower speaking tones than reported in literature [8, 23, 7]. It has been suggested that present-day practice, cultural changes [25] but also the type of speech material used and other methodological aspects might affect the speaking fundamental frequency [2]. We detected pitch frequency during running speech at a soft (ton1/vol1) and conversational (ton2/vol2) level, while others determined speaking fundamental frequency during production of sustained vowels or

during reading [28, 14, 8].

Our measurements were focused on the real demands of the subjects voices: vocal performance in raised and loud speaking. To obtain comparable data between and within individuals, we recommend to measure the speaking fundamental frequencies at absolute intensities of 60, 70, 80 and 90 dBA rather than at "soft, normal and loud" intensities. We observed that voices characterised by a 30 dBA span in general show less than 6 semitones rise at 80 dBA and less than 12 semitones rise at 90 dBA speaking (specificity 82.5 %). These data suggest that the subjects with such voice performances can be loaded with voice demanding activities (teaching, selling, managing).

In conclusion: analysis of loudness and pitch in standardised speaking tasks yields identifiable information about individual voice performances. To constitute more about individual voice capacity, this investigation has to be continued and validated in subjects with abnormal voice performances. The presented method and results here seem suitable for quantitative documentation of speaking voices in general, and might have a clinical application as well.

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Chapter

7

**Speaking voice: impact of intensity upon pitch
in strong and poor voices**

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Submitted

ABSTRACT

In sequence of a study in subjects with normal voices, this study reports about the impact of speaking intensity upon pitch in professional speakers (strong voices) and in adults with vocal complaints with and without voice therapy (poor voices). In the group of strong voices, the fundamental frequency rose by 1 semitone per 10 decibel interval (irrespective 60 to 70 dB, 70 to 80 dB or 80 to 90 dB). In the group of poor voices, a rise of 3 semitones over the first decade and 6 semitones over the second decade of intensity increase was observed; they were unable to reach intensities within the range of the third decade. The patients prior to voice therapy rose by 4 semitones over the first decade and by 9 semitones over the second decade. After voice therapy the pitch rise diminished to 2 semitones and 4 semitones respectively.

INTRODUCTION

In a phonetogram the entire fundamental frequency (F_0) range and the softest and loudest phonations on preselected frequencies are depicted. It presents the physiological range of a voice and is a reliable graph of the voice capacity [25, 13, 5]. However, a methodological problem occurs during the acquisition of the data: subjects who increase the loudness of a frequency also tend to raise the voice fundamental frequency. In case of a classical phonetogram this problem of adaptation F_0 on intensity is reduced by instructing the subjects to suppress this phenomenon, which requires either a good musicality of both subject and experimenter or a visual feedback of the actual F_0 . In recently developed automatic phonetography procedures, the phonation intensity is plotted as a function of the *actual* fundamental frequency [23, 21, 15].

Based upon the previous considerations, the meaning of the phonetogram contour for daily life activities might be limited or different: varying phonation intensity on a steady frequency is a rather unphysiological condition. The phonetogram will inform us about the intensity and frequency range, but the result will be strongly affected by the primary voice control capabilities. Valuable information about habitual,—and everyday—voice production might get lost due to the procedures followed (pitch control during decrescendo-crescendo is a training item during singing education, but not during running speech).

A number of studies have discussed the relationship between maximum range profiles obtained by phonetography and speech activities. Speaking activities use the inner vocal area and not the vocal contour and special procedures had to be developed to evaluate the speaking voice characteristics. Seidner [26] concluded that the "speech voice profile" can not simply be derived from "the singing voice profile". Hacki [14] observed that the normal speaking voice is located in the lower third area of the phonetogram of the singing voice, but no significant correlations between the data found by analysis of speech and those obtained by phonetography could be shown. However, in line with the previous considerations, a straight forward comparison is difficult as the speaking voice characteristics are obtained by registering F_0 as a function of phonation intensity, whereas the phonetogram data were obtained by registering phonation intensity as a function of F_0 . Pabon [20,21] applying real time phonetography by registering the actual fundamental frequency and sound-pressure level (F_0 /SPL) relationships, observed that the average F_0 during speaking is normally located in the center of the first octave of the phonetogram range. The precise location of F_0 /SPL combination appeared to depend on the instruction given to the subjects. The covariation between F_0 and SPL is found in most aspects of phonation and is reflected in the phonetogram contour, in register breaks and in the speaking voice distribution. In a louder SPL the distribution of speech production will shift upward to a higher F_0 .

Gramming et al. [12] quantified this changes in voice pitch during loudness variation with white noise in earphones while reading texts: a pitch rise by about a half-semitone per decibel sound pressure level was observed; singers appeared to change voice pitch

more than the nonsingers. They explained this finding by an easily available wider range and a use of pitch without stressing the voice. In order to evaluate the speaking voice characteristics more in detail and to allow comparison with data obtained from phonetography, we reported recently about the relationship between F_0 and SPL in normal subjects without voice complaints [4]. As the loudness level is a dominating factor in vocal stress and vocal fatigue, we now present a study in which the F_0 /SPL relationship is quantified in trained professional speakers (actors and speech therapists), in "normal" subjects with voice complaints but without voice therapy (subclinicals), as well as in patients before and after phonosurgery and voice therapy. The purpose of this study is to examine if strong voices increase loudness with less "automatic" pitch increase and if poor voices do need more (relative) F_0 rise. It is also explored in this patient group if there is a therapeutic effect on the F_0 range and /or on the pitch rise in louder speaking.

SUBJECTS AND METHOD

Subjects

After informed consent 122 subjects and patients participated in this study.

Group **A** consisted of 65 healthy subjects without any voice complaints or history of laryngeal disorders. Ear, nose and throat abnormalities were not observed by routine examination. 33 were students of the Academy of Acting (**actors**, mean age = 23 years, SD = 2) and 32 were professional speakers (actors, speech therapists, teachers and sellers) with a large vocal load during many years (mean age 39 years, SD = 6). The students received at least 2 years of training (5h/week) by voice teachers; the certificated speakers had many years of training and/or practice so that a proven good voice capacity is being accepted.

Group **B** consisted of 15 subjects (**subclinicals**, mean age = 30 years, SD =9) that volunteered for this study through public announcement for subjects with poor voices. They reported the occasional occurrence of a sore throat or tired voice, usually at the end of the day. Some of them also mentioned hoarseness after moderate vocal use. None of these subclinical subjects had ever consulted a speech therapist or doctor in relation to their voice complaints before. They had not been exposed to any voice related therapy, but had accepted their poor voice as a minor inconvenience with which they could live.

Group **C** included 42 speakers (**patients**, mean age =26 years, SD = 5) with vocal strain, vocal overuse and benign vocal fold lesions requiring phonosurgery and logopedic voice therapy (6 to 48 sessions).

Table 1: Subjects, gender and age.

type	total subtypes	gender		age	
		males	females	mean	SD
A: actors	33	9	24	23	2
	32	12	20	39	6
B: subclinicals	15	-	15	30	9
C: patients	42	16	26	26	5
Total	122	37	85	29	6

Table 2: Patients (n = 42) diagnoses of vocal fold pathology.

Diagnosis	female	male
Nodules	13	1
Polyp	1	6
Reinke Edema	2	-
Unilateral swelling	2	1
Cyst	4	2
Pseudocyst	1	2
Sulcus	2	3
Vergeture	1	1
Total	26	16

Method

After information and introduction, all subjects were fully aware of our interest in their loudness performance during speech; it struck some of them that phonation pitch rised with increasing loudness. We instructed these subjects to neglect this normal side effect of louder speech.

Phonation intensity and fundamental frequencies (F0) of speech were measured during conversation mode and not during reading a text or sustained phonation. Both, intensity and F0 fluctuate continuously during normal conversation [17, 28], which complicates quantification and averaging. Therefore we analysed Fo/SPL during connected counting (29-28-27...) which is considered for conversation with reduced prosodic and intonation features.

Prior to the maximum performance test we detected the habitual speaking intensity in all subjects by a Sound Level Meter (Quest Technologies, Model 2400). The F0 was displayed on the Autochromatic Tuner (Korg Electronics, Model AT 12, for more details on the equipment and procedures, see [4]).

In all subjects the semitone/decibel ratio (ST/dB) was detected. Reproducibility of the ST/dB measurements was performed 2-3 months later for the subclinicals (group B) and the patients (group C, on the waiting-list for phonosurgery). The effect of therapy (phonosurgery and logopedic voice therapy) upon the ST/dB ratio was evaluated by measuring the ST/dB ratios a third time, 4 -7 months later at the end of the therapy.

In this study loudness is used as the independent variable whereas the phonation frequency is monitored during five loudness levels of speaking. The procedure of exploration the intensity range of speaking is in line with the ideas of Pahn et al [22], Seidner [26,27], and was defined as follows:

- first: volume 2: on a comfortable level as is done in case of a normal conversation between 2 or 3 persons
- next: volume 3: on a loud standard level as is done in case of a meeting with 10 to 12 persons
- next: volume 4: on an even louder level, as is done in case of giving a lecture for an audience of 25 to 30 persons
- next: volume 5: at maximum loudness as calling numbers in a full house without microphone
- finally, volume 1: at minimal loudness, as is done in case of exchanging a confidential message to another person

Statistical analysis was performed by using SPSS version 7.52 for Windows (Mann-Whitney U test, Wilcoxon Signed Rank Test). Differences were considered significant when p was smaller than 0.05.

RESULTS

In case of comfortable conversation **pitch** ranges from ST 32-35 for males (actors and patients) and from ST 42-45 for females (actress, subclinicals and patients). At soft speaking (volume 1) pitch decreases still 2 semitones but remains 5-6 semitones above the lowest possible pitch (ST 27 with SD = 2 for males and ST 36 with SD= 2 for females).

Actors have their average loudest speaking pitch on ST 48 (SD=1) and this is still 17 semitones below their highest pitch. They have a speaking tone range of 16 semitones and an overall voice range of 38 semitones.

Male patients have their loudest speaking pitch on ST 43 (SD= 3) which is 12 semitones above softest speaking pitch and only 8 semitones lower than their highest pitch. They have an overall voice range of 24 semitones.

In the female group the loudest speaking is on ST 54 (SD=1) for actresses, on ST 51 (SD=3) for subclinicals and on ST 50 (SD=4) for patients. They have a speaking tone range of 14, 10 and 11 semitones respectively and an overall voice range of 31, 24 and 24 semitones.

Figure 1: Speaking voice track in actors and patients.

Figure 2: Speaking voice track in actresses, patients and subclinicals.

The **volume** of conversational speech is found at 68 dB with a SD of 2dB for males and 3 dB for females. This volume shows no significant difference between strong and poor voices. Decreasing the speaking volume to as soft as possible, group A diminishes the volume to 58 dBA (SD = 3), the subclinicals to 62 dBA(SD = 4) and the patient group to 60 dB (SD=2). With increasing volume, the performance between the groups becomes more and more different. Also variability within the groups became more apparent. Upon speaking as loud as possible, actors reach a volume of 100 dBA (SD=2), male patients 84 dBA (SD=6), actresses produce 95 dBA(SD=2), subclinicals reach 84 dBA (SD=8) and female patients 85 dBA (SD=6). Statistical analysis showed that actors and actresses reach significant more volume ($p<0.05$) Consequently the difference in Intensity Range of Speaking (IRS) between strong and poor voices is also significant: actors command a range of 42 dBA (SD= 3) and male patients a range of 24 dBA (SD=5), actresses possess a range of 37 dBA (SD= 4), female patients 25 dBA (SD= 7) and suspects 22 dBA (SD= 4).

During second and third measurement the following results are obtained:

- in group B no significant changes in loudness, pitch ranges and semitone /decibel ratio are observed over a period of 3 months (Wilcoxon Signed Rank test, $p<0.05$)
- in group C the second measurement after 3 months waiting list shows no significant changes in maximum loudness (volume 5), highest pitch and ST/dB ratio for the whole group. However, in 4 individuals maximum volume was decreased significantly and in 4 other highest pitch was diminished significantly. After therapy (phonosurgery and logopedic voice therapy) the third measurement presents the following results :
 - male patients had a significant increase of highest tone ($p<0.05$)
 - female patients had a significant increase of highest tone and volumes 4 and 5; as a consequence the semitone /decibel ratio also decreases significantly when speaking 20 dB louder ($p<0.05$)

Figure 3: Speaking voice track in female patients before and after therapy.

o before therapy

* after therapy

The **pitch range** of speaking over the five volume levels fluctuates about 1 octave: strong voices do not have to break into this (sub)maximum, subjects with poor voices have to use more their (sub) maximum. Moreover, group A commands a significant

larger tone range of the (speaking)voice and the same loudness increase they will do with less (relative) pitch increase.

The **intensity range** of speaking varies about 30 dBA; it should be more for strong voices (group A) and less for poor voices (group B and C). Males have a significant greater intensity range of speaking than females ($p<0.05$).

Concerning the relation or impact of intensity in speaking upon F_0 we see that strong voices rise less semitones than normals, and normals rise less than poor voices. The difference between groups becomes more significant the louder the subjects have to speak.

Figure 4:

Fig.4 Rise in semitones (ST) when increasing the volume of speaking

At the loudest speaking, the mean pitch rise is 12 semitones. When the maximal pitch rise is smaller than one octave (eg. 9 semitones), the loudness gain will be a discriminative factor: strong voices have already reached a volume gain of minimal 30 dB and poor voices have a volume gain of maximal 25 dB.

DISCUSSION

Normal versus pathological morphology can be distinguished by an ear, nose and throat examination and laryngoscopic or stroboscopic evaluation, whereas a logopedic examination evaluates the vocal behaviour such as breathing patterns, resonance coupling, speaking rate, (supra) laryngeal area muscle strain or compression, vocal onset etc. In contrast no clear cut quantitative methods seem to be available to allow a discrimination between strong, poor and normal speaking voices. After all, many subjects do not have to sing but have to speak for many hours a day. Although the speaking voice represents only a small portion in the total vocal area and gained therefore less attention in research, speaking certainly is the most important communication activity. As phonetographic contours are considered to be related to overall/singing voice capacity [25] it is good to investigate the surplus value of speaking performances.

Concerning vocal output -determined for a sustained phonation on vowel [a]- Colton's data [6] indicate that the maximum vocal SPL is greater for the modal than the falsetto register and that the average "comfortable" phonation frequency is located in about the middle of the speakers fundamental frequency range. This study of speaking voice performances in the chest and modal register indicates that comfortable and loud speaking in poor voices demands a relatively larger proportion of the fundamental frequency range than in strong voices.

Gramming et al. [11] found an increase of about 0,4 semitones per decibel (=12 ST/30dB). Our results confirm this relationship. First, subjects with poor voices show a larger rise of the fundamental frequency per decibel than subjects with strong voices. Second, the fundamental frequency increases more at high intensities, and the difference between strong and poor voices become more apparent at higher intensities (fig. 4). Subjects with less than 30 dB speaking span require more than 9 semitones per 20 dB and most probably have voices that cannot be charged with voice demanding capacities. Subjects with a speaking span of minimal 40 dB require less than 9 semitones per 40 dB and seem to be well equipped for voice demanding professions.

Voice volume capacity in normals is significantly larger than in patients ($p < 0.05$). The subclinical subjects (group B) show a performance even worse than the patients (group C) and resemble the patients more than the normals. This might be explained by the observation that treatment improves the voice performances in our patient groep whereas the subclinical subjects were not treated by definition. Pitch rise on a 20 dB increment is greater for the subclinicals and patients (9 ST), than for treated patients (6 ST) and normal voices (5 ST), and definitely greater than for strong voices (2 ST). On 30 dB increment the differences between poor, normal and strong voices become even more apparent (see figure 4). We conclude that measurement of the loudness levels that can be reached gives some indication of voice capacity, but evaluation of how this loudness level is reached -by monitoring pitch rise- is a more appears to be a more valid indication of voice capacity.

Pahn et al. [22] indicated that vocal sound pressure level is an important factor in the vocal penetrating capacity. They used intelligibility scores of spoken words at different intensities of white noise masking. At a masking level of 80 dB, "large voices" can be understood for more than 50%. Medium voices are understood for 50% at a masking level of 75 dB and small voices at levels of only 70 dB. So, strong voices have more power and volume and can resist louder noises.

Speakers alter their vocal production under environmental circumstances [28] which can be considered as a normal adaptation to maintain intelligible speech and communication. Inappropriate pitch rise seems to be not only a matter of simply poor speaking pitch control, but it could be an indication of limited voice capacity and overstrain of the voice. People with a great phonatory volume show a relative small pitch rise upon louder phonation; however the limited extent of the rise has to be considered as a distinctive feature of a good voice capacity.

The dependence of changes in mean fundamental frequency and mean phonatory sound level, before and after voice treatment, was studied by Åkerlund [1] in 33 patients suffering from nonorganic dysphonia. During reading texts at three different vocal loudness levels, the mean sound level in female patients increased after therapy. Concerning the contours of the phonetograms Åkerlund found significant changes before and after therapy in patients reading a text during masking by white noise: female patients showed a large increase of fundamental frequency, males showed a somewhat smaller increase. Due to treatment, Gramming [11] found improvements in the upper contour of the phonetogram for female patients which were not observed in the speech tests. This illustrates that speech tests evaluate other aspects of voice characteristics than the phonetogram. Similarly, Awan [2] found no significant correlations between phonetographic and speech F0-dB measures, except for a correlation between overall intensity range and F0 range. A major point of interest is to find out which training techniques will affect F0 and intensity, and which vocal training will improve vocal capabilities; research should also be focussed on the efficacy of training in untrained, beginning, intermediate and in advanced vocalists/singers.

Because of the greater vocal volume of males [18, 8, 7, 3] and their greater span of speaking volume, males will have fewer complaints than females in case of equal demands. This corresponds with the higher incidence of voice complaints in females (66%) compared to males (34%) [9, 16, 24, 10]. We observed a similar difference in incidence, although the distribution depends upon age: in the category 20-29 years we find 79 % females and in the category 50-59 years this diminishes to 54%. This range suggests that complaints in young (female) patients are due to overuse and vocal load or lack of voice training. But why should (young) females be at risk for vocal fatigue? Factors as voice behaviour and psychological wellbeing are mostly mentioned, but fundamental frequency and laryngeal anatomy (incomplete glottal closure and nodules, see Table 2) also seems to contribute. Comparing average F0 outside and inside the classroom, Nittrouer et al. [19] showed an increase as much as 100 Hz during the lessons. However, as can be concluded from this study, this is not a problem of wrong vocal habits but merely a natural consequence of louder speaking.

CONCLUSION

Analysis of intensity and frequency performances during speaking clearly yields information about individual voice capacity. The method and standards seem suitable not only for individual clinical use but also for more quantitative documentation of speaking voices: strong voices rise less semitones than normals and normals rise less than poor voices. The differences between the groups become more apparant the louder the subjects have to speak.

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Chapter

8

**Voice performances in female teachers
with or without voice complaints**

R. Buekers

Submitted

ABSTRACT

Prediction and selection of strong or poor voices is a problem of finding adequate definitions and criteria. Laryngological examination is self-evident, but voice function tests have even more significance. Female teachers with (n=20) or without (n=30) voice complaints were selected and pitch and loudness performances of speech were compared. The results show significant differences in the speaking performances of both groups. Female teachers with voice complaints since the beginning of their occupation have an intensity range during speech of less than 30 dB and a pitch range of less than 24 ST. Female teachers without voice problems during their teaching career have an intensity range during speech of more than 30 dB. If they have an intensity range of more than 44 dB and a pitch range of more than 31 ST they are the ideal person for professions demanding a strong voice.

INTRODUCTION

In many professions there is an increased demand for oral communication. Not only are good speaking skills a necessity, it is often equally important that the person's voice be strong and clear. Particularly in professions where a person has to speak loudly for several hours per day (e.g. teachers) it is not sufficient to just have a clear voice, a person also needs a strong vocal system. Only a few professions focus attention on voice capacity during recruitment or training. In some cases, an ear, nose and throat exam or a speech and voice test are required. However, results obtained this way and the criteria used to interpret them vary widely and for the most part have an insufficient scientific basis [1].

It becomes especially hard for somebody who despite voice complaints such as voice fatigue or hoarseness would like to pursue a 'speaking' profession. The question arises whether there are any objective norms to define this person as capable, partly capable or incapable of performing in this line of work. First of all it is necessary to determine the present or future demands on the person's voice. Vocal load is measured in terms of time and intensity: the longer and louder a person has to talk, the greater the strain on the voice will be and the more voice capacity is needed. A voice accumulator can be used to measure the exact level of vocal strain and has been applied in a number of professions [2].

Furthermore, the voice capacity of the person in question (applicant) should be determined as it differs from one individual to the next: some people become hoarse after talking for 30 minutes while others can teach for hours without any problem. Faulty or correct voice techniques cannot fully account for this. Several factors come to mind, such as: discrete abnormalities on larynx or the vocal system; slight anterior swelling of the vocal cords; incomplete posterior or glottis closure; asymmetric laryngeal structures with desynchronisation or limitation of the vibration of a certain part of the vocal cord (3,4,5). These are all abnormalities which will only appear when the voice is strained above normal and they could then be held responsible for a reduced voice capacity and occurring voice complaints. Larynxes which at first glance appear 'normal' but yet show a reduced voice capacity, require a complementary stroboscopic examination together with a phonetogram [6,7,8]. The predictive and prognostic value of this kind of voice function testing will become increasingly obvious as soon as 'Phonometry' (measurement of voice performance) will supplement phonetograms and in turn become equally important as audiometry is for the ear.

From the very beginning, it was decided to recruit female teachers for the testing as they make up the largest group in the teaching profession [9,10], and they suffer the most from professional dysphonia [10,11]. The aim of the study was to determine the difference in voice capacity between teachers with voice complaints versus those without while they are performing their profession. It would have been ideal to do a

prospective long term study on teacher trainees. However, the results presented here were concluded from a profile done on teachers who had had no voice problems during at least 10 years of teaching versus a group of young teachers who had been affected by such problems right from the start of their career. In the latter group there was an excessive strain on the voice resulting in decompensation within a short period of time (12,13). According to our definition this is rather a case of selecting the wrong occupation than a case of occupational dysphonia and a voice selection test would have been useful prior to choosing their occupation (14). Teachers who at a later time developed voice problems due to excessive strain obviously started out with a good voice. For this group voice selection testing would not have shown the desired results.

SUBJECTS, MATERIAL AND METHOD

Subjects

Selection of teachers without voice complaints (Group 1) was done by sending a letter and questionnaire to 275 female teachers employed by 6 secondary schools. The letter contained a brief description of the aim of the study, while the questionnaire inquired about issues such as the frequency of voice problems. Candidates who stated that they had been teaching for more than 10 years and seldom or never had any voice complaints were temporarily assigned to the 'normal voice' group. Of the 97 teachers (35%) who returned the questionnaire, 34 (35%) were prepared to undergo a short voice screening test according to Boone [15]. Of these 34, 30 women received normal scores and were selected for group 1 as teachers with no voice complaints. These women worked at least half a day, ideally whole days. Since the selection criterion for this group was an employment period of at least 10 years, the personal data concerning age and number of years employed differed from Group 1.

Chart 1: Age and number of years employed Group 1 and Group 2.

		Group 1 (n=30)	Group 2 (n=20)
Age	M	43	28
	SD	6	5
	R	34-55	23-40*
Number of years employed	M	21	6,5
	SD	5	3
	R	12-33	1-15

Teachers with voice problems (Group 2) were selected by contacting speech therapists. A total of 20 teachers agreed to take part in the study and were examined. All of them being former patients of ENT practices with the diagnosis vocal nodules (12x), laryngitis(3x) and functional dysphonia with insufficient (posterior) glottal closure (5x). They had all received speech therapy due to voice complaints and insufficient voice capacity. The goal was to fulfil the vocal demands required in the corresponding line of work by improving vocal techniques.

Instruments

A dB meter (Bruel & Kjaer 2232) was used to measure sound **intensities**. A dB(A) filter was used so that low frequency sound components had less influence on the measurements. Sound intensities between 34 and 130 dB can be measured and appear on a digital display. Average values of each test were determined using the Leq (level equivalence) function. **Pitch** was measured using a Korg AT 12 autochromatic tuner. This device, serving the tuning of instruments in the professional music world can measure frequencies of between 32.7 (semitone 12) and 3950 Hz (semitone 95). The pitch is measured with the help of a little light which flashes underneath a certain note and the corresponding octave. Research by Solberg et al. [16] revealed that this device is clinically equally as suitable as other more sophisticated equipment to measure fundamental frequencies.

The tests were conducted in a room with 'living-room acoustics' (curtains and/or carpets) and with a background noise of 40 dB maximum. The microphone of the dB meter was held 30 cm from the subject's mouth [17].

Method

Two people conducting the experiment were in charge of the 50 subjects. Each of them worked independently with one group. As there are various approaches to the determination of the values mentioned, it seems important to precisely describe our method:

During the introductory interview with the teacher, voice level and intensity were measured by pitch decoder and dB meter. In the first test the subject was asked to count and hold the "a" of "acht" (like "a" in jar.), because sound level and intensity vary very little in that particular situation. During this test the mean value can then be determined using the mean/hold function (see co-ordinate 2 on the score sheet).

During the next test the pitch range was measured. The subjects were asked to produce a descending tone starting with a speaking frequency and descending as low as possible (<). Then they were asked to start at normal speech level and produce an ascending tone to as high as possible (>). This could be repeated if necessary and demonstrated by the test conductor. The lowest and the highest tones were marked on the score sheet.

The third test determined the intensity range of the speaking voice. Subjects were asked to count 21 up without interruption. Normally this corresponds with the previous measured pitch and intensity co-ordinate [2]. Now the subject was asked to count more loudly. Pitch level and intensity were also noted as co-ordinate 3 on the score sheet. This step was repeated one more time asking the subject to speak even more loudly (co-ordinate 4) and then as loud as possible (co-ordinate 5). Finally, they were asked to count as softly as possible (co-ordinate 1) without whispering. By the end of the test, the following measurements had been recorded:

1. intensity range: number of dB between intensity 1 and intensity 5
2. pitch range: the number of semitones between < and >
3. the increase in semitones by which the speaking voice rises when one speaks 30 dB louder than usually or when one reaches a volume of 85 dB.

This procedure made it possible to express the voice capacity in one value. Included in this value were intensity range, total pitch range and the amount of semitones by which the voice rose between 60 and 85 dB. The voice capacity was obtained by use of a discriminative analysis. We selected the variables which allowed the ideal distinction between people with or without complaints. Based upon this analysis the speaking voice capacity as defined by subjoined formula was found to be the most discriminative parameter. The combination of these 3 variables is a superior means of discrimination to one variable by itself.

Chart 2: Formula for speaking voice capacity.

$$S.V.C. = \frac{\text{Intensity Range of Speaking} \times \text{number of semitones}}{\text{Increase of semitones (at 85 dBA)}} = \frac{dB(A) \times ST}{STST} = dB(A)$$

Statistical evaluation

The data was analysed by use of SPSS version 7.5 (SPSS Inc.). The group differentiations were evaluated by means of non parametric tests (Mann-Whitney U Test, Wilcoxon Signed Rank Test). Classification of subjects with or without voice complaints based upon the speaking voice capacity formula was performed using a K-Means Cluster analysis.

RESULTS

Chart 3 describes the mean values (M), standard deviations (SD) and range (R) of those teachers without voice complaints (Group 1) and those with (Group 2). Intensity range of the speaking voice in dBA, pitch range in number of semitones and pitch increase in semitone at an increased level of 30 dB or to a total of 85 dB where it was not possible for the subject to increase her volume 1 by 30 dB or more. Groups 1 and 2 differ statistically significantly. The data marked with an asterisk reflect a significant statistical discrepancy between Group 1 and Group 2.

Chart 3: Results of 30 female teachers without voice complaints (Group 1) and 20 female teachers with voice complaints (Group 2).

	Intensity Range of Speaking (dB)	Pitch ran- ge (ST)	Increase of semitones at an intensity of		Speaking Voice Capacity (S.V.C.)	
			85 dB	vol 1 + 30 dB	vol 1 + 20 dB (x = 77 dB)	85 dB
Group 1 M	43*	30**	10	12	200	136***
SD	4	3	2	3	76	50
Group 2 M	32*	23**	10	-	151	75***
SD	5	6	3	-	97	28

Figure 1: The mean results of Group 1.

Figure 2: The mean results of Group 2.

Figure 1 (Group 1) and figure 2 (Group 2) show a graphic representation in the phonotogram score sheet of the average results of pitch increase at the five speaking intensities. The statistical evaluation showed an average **intensity range** between volume 1 and volume 5 of 43 dB (SD=4) in Group 1 and 32 dB (SD=5) in Group 2.

The difference of 11 dB in favour of Group 1 was significant and it was therefore tested using the T-test for unrelated variables. The difference between the two groups was significant at a level of $p < 0.05$. The pitch range in semitones was 30 ST (SD=3) in Group 1 and 23 ST (SD=6) in Group 2. The difference of 7 ST was significant at a level of $p < 0.01$. Statistical analysis of the pitch increases in the two groups show that increases of 10, 20 and 30 dB at the most were not independent variables. There were no significant discrepancies between the two groups. However, we did find that the women with voice complaints were only able to amplify their speaking voice by 30 dB in very rare cases. Because of the obvious difference in the number of people in both groups who were able to amplify their choice by 30 dB, it was now possible to calculate the sensitivity and specificity of the test procedure. In Group 1, 100% of the teachers were able to produce this amplification, whereas 75% of Group 2, were unable to amplify their speaking voices by 30 dB. The likelihood for this test result to be negative (abnormal) for a voice bearing little stress is 75% sensitivity. The likelihood of this test result being positive (normal) for a voice bearing normal stress is 85% specificity.

We also compared the pitch increase within the two groups at the 85 dB level (the average maximum level in Group 2) but here as well, there were no statistically relevant discrepancies. Based on our 5-95% analysis, teachers with an intensity range less than 34 dB were assigned to Group 2 and teachers with an intensity range of more than 44 dB to Group 1. When the pitch range is smaller than 24 semitones, the teachers were assigned to Group 2 and a pitch range of more than 31 semitones subsumes the teachers under Group 1. The combination of these factors (intensity range x semitone range / semitone increase) at an intensity **increase of 20 dB** (e.g. from 57 to 77 dB) results in a speaking voice capacity of 200 dB (SD=76) for Group 1 and a speaking voice capacity of 151 dB (SD=97) for Group 2. At this level there was no statistically significant difference.

Figure 3: Speaking Voice Capacity at 77 dB.

◆ Female teachers without voice complaints (Group 1, subject 1-30).

▲ Female teachers with voice complaints (Group 2, subject 31-50).

Figure 4: Speaking Voice Capacity at 85 dB. ♦ Female teachers without voice complaints (Group 1, subject 1-30). ▲▲Female teachers with voice complaints (Group 2, subject 31-50).

Compared at a **85 dB speech level**, Group 1 had an average speaking voice capacity of 136 dB (SD=50) and Group 2 of 75 dB (SD=28) (See fig.4). Based on the formula for speaking voice capacity there was a significant discrepancy ($p<0.000$)between Group 1 and 2 at 85 dB (see also chart 3).

The best result of the 5-95% analysis was obtained with the combination of volume **increase of 30 dB**, **pitch range** and **intensity range**. This placed 90% of the teachers without voice complaints in Group 1 and 80% of the teachers with voice complaints in Group 2. Five percent of the members of Group 2 could not be accurately be assigned with this method. In figure 5 they are specified as group 0.

Figure 5:

DISCUSSION

A global comparison of the results of the two groups showed that the teachers in Group 1 could all increase their speaking intensity by 30 dB, whereas only five of the teachers in Group 2 could do the same. The remaining 15 women in Group 2 achieved a maximum amplification of between 20 and 30 dB louder than conversation level. These results support the conclusions of other studies (18,19) which have found the level of amplification of the speaking voice to be an indicator for the amount of strain it can bear. If someone can amplify their habitual speaking voice by 30 dB or more than that person has an excellent chance of being able to execute a speaking profession. A person, however, which cannot raise her voice by 30 dB while speaking for a prolonged period of time, will reach her maximum speaking capacity more quickly and will most likely develop problems in the long run.(20)

Our study showed significant discrepancies between teachers with or without voice complaints.

The **intensity range** of the normal/average speaking voice was between 20 and 30 dB [21]. Teachers without voice complaints scored higher and their voices were stronger. The majority of teachers with voice complaints scored within the average range. When their voices were more exerted, the risk of voice complaints increased accordingly.

An average voice has a **pitch range** of between 18 and 30 semitones; a poor voice has a lower and a strong voice a higher range [20,22,23]. We established that the pitch range of female teachers without voice complaints was close to 30 semitones, while that of female teachers with voice complaints was fairly close to 18 semitones.

If the volume increases by 20 dB, the average **pitch increase** is seven semitones (SD=3). Our two groups fell within the average range. However, in the group of female teachers with voice complaints, two subgroups could be distinguished:(see also fig.3)

2a Six subjects had an average pitch increase of only three semitones but yet they had a large speaking voice capacity of 296 dB (SD=23). These six teachers had strong voices but they probably entered group 2 on the basis of other factors (stress, respiratory infections, chronic obstructive pulmonary disease, hyper-reactivity, etc.)

2b The remaining 14 subjects had an average pitch increase of eight semitones and a speaking voice capacity of an average of 89 dB (SD=23).

A comparison of both groups at 85 dB (maximum capacity of Group 2) showed no significant discrepancy regarding pitch average (see also chart 3). A volume increase of 30 dB and a pitch increase of 12 semitones constitutes a normal performance. We determined that only the female teachers without voice complaints were able to comply (85% specificity).

The lack of significant differences between the two groups regarding pitch increase could be explained by the fact that all teachers with voice complaints had received

increase with speech therapy, we have observed in patients that they can learn to amplify their speech with less pitch strain (i.e. less pitch increase with the same intensity increase). It would have been interesting to have measured the voice performance of the teachers in Group 2 before they had received speech therapy. However, this was not possible for the present study design in which we looked for practising teachers with voice problems. Unfortunately, quantitative voice data or phonetograms from before the therapy were not available.

The relationship between pitch increase and volume increase [24] is not linear but rather exponential. Yet, our data showed that increases in pitch varied somewhat depending on whether a person increased her volume from 60 to 70 dB, from 70 to 80 dB or from 80 to 90 dB. In the first step, 3 semitones (SD=2) were normal; in the second step, 4 semitones (SD=3) were normal and in the third step, 5 semitones (SD=3) were normal.

To determine the correct pitch, it seems important to consider the voice volume as well. People with a loud voice, need not to be concerned as long as they have a wide intensity range. This is usually accompanied by a wide pitch range which can act as a buffer to avoid excessive muscle strain. Since men have a greater voice capacity [25,26,27], they will probably run less risk of developing problems than women with the same voice demands. This might be a partial explanation for the higher prevalence of voice fatigue and voice problems in women.

Increasing the pitch while teaching is often considered to be an incorrect speaking habit, however, it is really a 'side effect' of speaking more loudly.

Speaking louder always involves a certain degree of natural pitch increase, but on the other hand, it has now become easier to establish whether the degree of pitch increase is too large or whether a person is speaking too close to her maximum capacity.

A pitch increase of 12 semitones (1 octave) usually defines the maximum speaking voice. It has generally been observed that people with voice complaints do not achieve an intensity increase of 30 dB by increasing their pitch by one octave, while people without voice complaints will have been able to increase their intensity by more than 30 dB before their pitch has increased by one octave. Apparently, weaker voices need to use more power and tension to increase the volume and this results in a more rapid increase in pitch.

CONCLUSION

When performing voice tests or making a prognosis of whether a person will be able to pursue a speaking profession without developing voice complaints, we recommend measuring the voice performance. Pitch and pitch range during speech at 60, 70, 80 and 90 dB loudness are valuable indicators. The maximum speaking volume is a valuable measure in itself and it will have more or less been reached when the subject has increased his/her pitch by one octave. If after an increase of 12 semitones the volume increase is less than 30 dB the capacity of the voice is considered small. If there has been an volume increase of 40 dB or more, the capacity is considered excellent.

Scientifically, more attention should be focused on the speaking voice. Both test participants as well as speech therapists regarded our test as a valuable supplement to the classic phonetogram. The above-described method was carried out with the aid of simple equipment and the results were clinically relevant. When measurements are taken before and after speech therapy, the effects of therapy on speech capacity can be documented and objectified. With some degree of caution, these results could also be used to help advise a person on his/her suitability for certain professions, or to evaluate whether a patient is ready to return to a speaking profession.

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Chapter

9

Perceptual evaluation of vocal behaviour

R. Buekers

This chapter is a slight revision of a submitted article

ABSTRACT

Speech therapists define their voice therapy by perceptual evaluation of vocal behaviour and speaking technique. In the diagnostic phase they identify vocal problems and they spot the imperfections which may be present. In their therapy they plan a course of action to remove them. While modifying vocal behaviour, they all treat aspects like hypo- and hyperfunction, breath control and support, voice onset, resonance and adjustment of vocal tract...

On the surface it seems they all agree in clinical diagnosis, but there have been no studies of consensus or agreement. This study analyses the parameters and the (inter - rater and intra - rater) reliability of perceptual evaluations of videotaped subjects by speech therapists. There is not only confusion about nomenclature which makes it difficult to compare the evaluation, but statistical analysis shows poor and less than moderate interobserver and intraobserver agreement in the assessment of voicing technique.

INTRODUCTION

Before starting voice therapy, the first step by speech therapists is always a check of **how** the voice is currently being used. This perceptual evaluation of speaking technique is focused on mode of phonation and this manifests (incorrect) voice production and starting points for voice reeducation. It requires a (more) visual examination of the patient to recognize aspects of vocal use. Therapists have a great skill in perceiving and describing vocal dysfunction and in determining the reasons for this dysfunction [20]. It is accepted that these observations of speech therapists all agree in clinical diagnosis, but there have been no studies of consensus or agreement. It is also remarkable that the current literature gives no good definition of voicing style and no standard protocol how this can be evaluated. The speech pathologist is responsible for evaluating and treating abusing/misusing behaviours of the speaking voice [14] but her/his observation results and terminology is very often arbitrary, subjective, misleading and self-serving [13,8]. There are many reasons why instrumental analysis will probably not replace perceptual evaluations: high costs of instrumental techniques, at times discomfort for the patient and interference in voice production or involving interrelated physiological structures. The dynamics of the whole voicing system is clear: voice quality may be directly related to vocal anatomy, it is also related to dental occlusion, breathing pressure, pharyngeal constriction and vocal fold vibration.

Vocal behaviour is described with small and broad definitions in the literature and there is no consensus about what it is and how it could be tested. Some authors mention only physical or physiological aspects like vocal fold vibration and vocal fold interaction with airflow [18, 17, 5, 15]. Others emphasise the cortical and reflex control of respiratory muscles and of auditory feedback on voice and voice pitch [19, 7, 11]. Finally, clinical and artistic aspects of vocal performance are presented: hyper-(hypo-)breathing and support, the acoustical characteristics of the vocal tract, coordination of breathing, vocalization and resonance [6, 1, 4, 10, 12]. The Vocal Profiles Analysis Scheme [9] is a structured procedure to rate a speaker's vocal characteristics. It is based on a *phonetic setting* for research studies and not for ease of administration in clinical practice. Stemple [16] freely uses the terminology of vocal behaviour which applies to breathing patterns, vocal fold approximation, laryngeal compression adjustments and resonance coupling.

The motive for this study came out of our conclusion, we conducted before our trials on the Voice Interval Test, that there was no agreement between five speech therapists when they evaluated vocal behaviour of subjects. This study will investigate the following questions:

1. Which aspects of vocal behaviour are evaluated?
2. How is the inter - rater reliability score of the judges?
3. How is the intra - rater reliability score between the first and the second evaluation?
4. Do the reliability scores correlate with the amount of training of the judges?

METHOD

Twelve subjects, executing various speaking exercises during approximately 4 minutes each, were video recorded using the same procedures and equipment. These 12 subjects -7 females and 5 males- ranged in age from 24 to 50 years. Based on their history the following subgroups could be discriminated:

- 3 patients: two were previously treated and one was in voice therapy.
- 3 trained voices: one speech therapy student, one speech therapist and one diction coach.
- 3 good voices: one seller and two teachers without voice history.
- 3 normal voices: these subjects had normal voice use and case history.

The subjects were all unknown to the judges.

The evaluation of the voicing technique of the 12 subjects was first carried out in a pilot study using 15 judges. Eight judges were about to finish their studies in speech pathology and seven were certified speech pathologists with more than 2 years of experience; two of them had intensive practice in voice therapy.

The instruction was: "Describe the subject's voicing /speaking technique, not voice quality or acoustics, but phonation mode and voice production ". The judges received no formal training. This was a subjective description and categorical rating of vocal behaviour. Therefore this group received a blanko sheet with the number of the subject on the video and her/his first name and age.

A second evaluation took place 10 days after the first evaluation and followed the identical procedure. None of the judges was informed about their first evaluation.

A second study was done using the data from 51 judges. These judges comprised 18 students about to finish their studies in speech therapy, 23 speech therapists and 10 voice experts (speech therapists with postgraduate training in voice and more than five years experience in voice diagnostics and voice therapy). They all evaluated the voice production of the 12 videotaped subjects using the Voicing Evaluation Scheme (see addendum). This form gives systematic attention to the following three aspects of voicing:

1. **activator** (head position / movements, larynx position/movements, posture and breathing).
2. **generator** (voice onset, register, constriction, pitch, loudness and intonation).
3. **resonator** (jaw and articulation position/movements, vocal color and nasality).

Sometimes the judges had a multiple choice (e.g. breathing is clavicular, diaphragmatic, costal), sometimes they had to rate a characteristic feature on a visual analogue scale of 10 cm from one extreme to the other.

RESULTS

The pilot study evaluates which aspects of the voicing mechanism were described and if the speech therapists had a clear-cut concept of (correct/incorrect) vocal technique. They frequently described respiratory behaviours like breathing pattern (clavicular breathing or mouth breathing), postural aspects like hypotonic pelvis or tension in the neck and resonance adjustments like closed or dorsal articulation, insufficient nasality. Type of voice onset, register (modal, chest...) and other generator features were rarely mentioned as aspects of voicing.

Table 1 illustrates the ranking of voicing aspects as employed by these judges.

Table 1: Evaluated voicing aspects.

Voicing aspects	First evaluation percentage judges	Second evaluation percentage judges
breathing pattern	50%	57%
posture	40%	34%
articulation movements	25%	34%
voice onset	23%	10%
breath	10%	5%
flow pressure	10%	27%
pitch	8%	10%
breath-voice joining	7%	10%
register	7%	5%
vocal effort	5%	11%
airflow	4%	5%
intonation	4%	5%
breathing rythm	3%	-
loudness	3%	5%
resonation	2%	-
constriction	2%	-

By computing the Spearman correlation coefficients of each judge by the other judges we produced the degree of reliability between the judges. For the first evaluation the "correlation" was between 0.20-0.33 (See Table 2, correlation range between -0.11 and 0.55). The correlations of the second evaluation were even less (see Table 3, correlation range between -0.03 and 0.56).

	I														
I	2														
2	50	---	3												
3	.44	.38	---	4											
4	.42	.44	.33	---	5										
5	.45	.44	.35	.50	---	6									
6	.27	.19	.32	.40	.34	---	7								
7	.17	.33	.34	.32	.36	.42	---	8							
8	.38	.35	.47	.44	.36	.38	.38	---	9						
9	.26	.27	.30	.16	.17	.07	.08	.21	---	10					
10	---	.16	.03	.15	.01	.16	.03	.14	.02	---	11				
11	.14	.14	.08	.19	.17	.27	.25	.28	.05	.02	---	12			
12	.11	.16	.08	.09	.14	.03	.11	.13	.06	.00	.16	---	13		
13	---	---	---	---	---	---	---	---	---	---	---	---	---	14	
14	.40	.38	.23	.41	.37	.25	.32	.39	.20	.02	.23	.18	---	---	
15	.26	.30	.24	.36	.41	.29	.33	.42	.12	.15	.18	.13	---	---	

Table 3: Spearman correlations of the second evaluation.

Intrajudge agreement between the first and second evaluation of these judges was computed by the Cohen's kappa statistic method which takes chance into account. This calculates only the size of agreement as far as one topic is mentioned in observation 1 and in observation 2. The test-retest reliability values were poor and fair (see Table 4, mean kappa is 0,30 and kappa range was between 0.00 and 0.52).

Table 4: Cohen's kappa between judges' first and second evaluation.

JUDGE:	1	2	3	4	5	6	7	8	9	10	11	12	13	13	14
KAPPA:	0.43	0.40	0.37	0.46	0.33	0.44	0.39	0.34	0.00	0.19	0.27	0.01	0.00	0.52	0.37

The extended study using 51 judges and our Voicing Evaluation Scheme obtained the following results. The interreliability of the judges obtained a correlation of 0.49, in the generator aspects it was less ($r = 0.35$), in the resonator aspects it was highest ($r = 0.57$). The correlations for the second evaluation were no better, not for the whole group nor for subgroups of students or experts.

In the analysis of variance of the subgroups there were no significant differences between the speech therapists ($x = 7,3$ and $SD = 1,2$) and the voice experts ($x = 7,0$ and $SD = 1,6$). The students reached a mean score of 5,4 and a $SD = 2.0$.

Calculating this test- retest agreement, the speech therapists scored a $kappa = 0.73$, the voice experts' $kappa = 0.70$ and the students' $kappa = 0.37$. Looking at subdivisions of this evaluation, the agreement was highest for the resonator aspects and lowest for the generator aspects.

DISCUSSION AND CONCLUSION

Clinical evaluation of voice production has hardly been described in the literature. The current perceptual evaluations of voice made using a mixture of rating for voice quality, severity of dysphonia and voicing technique. Another problem is the variety in types of rating: categorical, interval, visual analogue... and the fact there is no standard task or stimuli and recording instruction. In our study, evaluation of voice production focused on visual identification of vocal technique; the use of video recordings also allowed listening and auditory input, but tactile inputs and specific/interactive tests were excluded. Observation and diagnostics of voicing resulted in highly variable and irreproducible scores.

The current dilemma that 2 speech therapists may reach a different diagnosis for the same patient, and consequently a different voice therapy, bears out when we look at ours results of insufficient correlations and less than moderate kappa's. Reliability

improved when the speech therapists used the same terminology and the same standard. The Voicing Evaluation Scheme standardises terminology and degree of dysfunction and takes a step towards a more objective evaluation. With regard to professional background and experience with voicing diagnostics, we distinguished two different results: the variance in speech therapists and voice experts is not significantly different (even a little better for the former) whereas the variance between speech therapists/voice experts is markedly better than in speech therapy students. Based on these results it would be interesting to base future research on how perceptual evaluation of voicing is learned and whether training of this perceptual skill would make it more replicable and reliable. It goes without saying that the above results do not pertain to necessity and quality of voice therapy and nor to exactness and validity of the evaluations. Therefore we still need documentation of (in)correct vocal behaviour by means of videorecordings and discussions between therapists and experts in order to diagnose voicing characteristics more accurately and with better agreement.

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Addendum Chapter 9:

VOICING EVALUATION SCHEME

1. Activator

	extremely deficient				excellent
Head / shoulder position	<hr/>				
Laryngeal position	<hr/>				
Posture	<hr/>				
	0 hypertonic	0 hypotonic	0 oversteering		
Breathing type	0 abdominal	0 costal	0 clavicular	0 diaphragmatic	
coordination with voicing	<hr/>				
	0 inspiration	0 phrasing	0 wasted air		

2. Generator

Vocal onset	0 soft 0 breathy	0 hard 0 creaky	0 coordinated 0 glottal attack		
Voice quality	<hr/>				
	0 rough	0 breathy	0 diplophonic	0 instable	
Register	0 chest	0 modal	0 head	0 falsetto	
Constriction	<hr/>				
	0 laryngeal	0 pharyngeal	0 mandibular	0 labial	
Pitch	<hr/>				
Loudness	<hr/>				
Intonation	<hr/>				

3. Resonator

Jaw / mouth opening	<hr/>				
	0 tensed	0 flabby	0 lateral		
Nasality	<hr/>				
	0 hypo	0 hyper	0 constricted		
Articulation position	<hr/>				
	0 excessive	0 flabby	0 mumbling		

Chapter

10

Summary and conclusions
Samenvatting en conclusies
Résumé et conclusions

SUMMARY AND CONCLUSIONS

A voice disorder (dysphonia) will often be caused by an abnormality of the vocal folds. A small lesion can cause a remarkable disability and simple surgery can do a miracle. With some (serious) dysphonias a laryngeal disorder can not be determined. Respiratory or resonance factors can influence the quality of the voice. Medical treatment or voice reeducation can generate a clear improvement, but the change is usually less spectacular and asks a lot of effort and discipline from the patient. There are also voice complaints caused by incorrect voicing technique: the complaint develops very insidiously, is usually broader than just the quality of the voice because fatigue and pain do also interfere. After a while the person experiences that the complaint is connected to the amount of vocal use. It is obvious to hold this excessive vocal load responsible for the complaints, but is this appropriate?

This "excessive" vocal load demands already effort for a longer time and will in the beginning be found normal, but later this vocal stress will be considered as cause of the complaints and the fatigue. The size of the extra effort depends of the weight of the demands (vocal load) and the availability of the capacity to complete the task (vocal capacity). The conclusion that so many patients attribute their voice complaints to vocal load was surprising and was the cause for many (unanswered) questions. The goal of this study was to gain more insight into the role of vocal use, into the mechanism of vocal load and vocal capacity, into the normative data to get more experienced advices about suitability, unsuitability or restcapacity of someone's speaking voice.

Chapter 2 reviews the literature about voice and voice disorders related to labour (occupational voice disorders). Ergonomic studies of speaking during occupation are scarce and usually focused on selected groups like for example patients or teachers and on selected parts like for example humidity level or influence of noise. For the time being there is little evidence about the influence of occupational conditions on the voice and these studies are often achieved under laboratory conditions.

The effects of vocal load recently got more attention. The vocal load index of speaking gives especially weight to intensity. The demanded voice quality and the content of the message will be important as well, but are till now not reflected in the formula.

In the epidemiology of occupational diseases voice complaints are seldom mentioned and this for two reasons: firstly because they are registered on disease and not on disability and secondly because people with occupational dysphonia are only a very small group compared to the amount of people with disability due to backaches, respiratory complaints or psychiatric disorders.

An effect is that occupational dysphonia has no attention and priority and even that no definition can be found. The distinction with a wrong choice of profession is important and essential is that there is a good voice in the first years of occupation and that the voice capacity will be reduced by the practice of the occupation. Will somebody with an initial good voice get vocal nodules by considerable vocal use?

There are no scientific studies that demonstrate this direct relationship and there is a believe that a lot of problems would not occur when the performances of the voice would be documented before.

These days the methodology of the examinations is set by estimation and the next chapters show that the objective measurements of voice performances and registrations on the workplace are possible.

In chapter 3 we proceed into the quantification of vocal use itself: registration of volume and speech duration in the natural working situation is possible thanks to the voice accumulator.

The development of the voice accumulator confirmed once again that the measurement of voice production has many traps, but it is possible to document the vocal demands of people engaged in the same profession, or in a specific situation.

Voice accumulation measurements were registered and analyzed with 6 people out of each profession with different vocal demands. The results of these measurements were slightly amazing for every party concerned, certainly for the test subjects. The researchers also had expected more vocal use. The condition for passing judgement on someone's (im)possibilities to fulfill a certain profession is the precise determination of the vocal needs for that profession. The usefulness of this quantification is shown in the fact that the subjective estimation differs from the objective measurements.

In chapter 4 we pay attention to a first aspect of vocal stress, namely examination of the laryngeal function. At this point we we had the opinion that electroglottography was a sufficient, non invasive research method of the vocal folds if a satisfactory analysis technique of the EGG signal was developed. Even the reproducibility of a standardized vocal sound was below average.

The EGG is cheap, the signal is very simple but is only useful as a measurement of the fundamental frequency and a few quality analyses like registertransition and voice onset. The EGG tells us something about the degree of vocal cord contact but the glottisclosure (opening) cannot exactly be precised with it: the way quantitative measures are calculated by some commercial apparatus, must be interpreted with great caution. EGG can only be used in combination with other apparatus and signal analysis. There are indications that the EGG signal has similarities with the jitter analyses of the acoustic signal but not with the shimmer values of the sound of the voice.

Chapter 5 is dedicated to endurance tests of the voice. Questions were raised at earlier experiences with voice stress tests in relation to the value of these tests.

The use of the voice is forced up in the Voice Interval Test. This is applied to 20 patients with voice fatigue complaints and to a reference group N=12 without voice complaints.

The test is conducted in a day of leave and in combination with an ordinary working day. Each time EGG, acoustic analyses and a pain and fatigue scale is done. According to these parameters there were no significant differences determined between both

groups. The clinical meaning of voice stress tests can be questioned. It also shows that vocal fatigue is something else than laryngeal fatigue. Vocal fatigue is a complex symptom of internal and external factors of motivation and appreciation, behaviour and attitude, labor stress, personal stress, lack of empathy, unappreciation... For the second time we conclude that subjective complaints are not confirmed by these objective measurements.

In chapter 6 and 7 further investigation has been done in interaction of loudness of speaking and pitch of speaking. In the voice pedagogy it is experienced that good voices while speaking louder, hardly or not at all increase in pitch.

In voice therapy it is known that patients by speaking louder increase the pitch too much. These facts are also recognizable in the fonetogram, more so when the speaking voice is engaged by the testing. In chapter 6 the results of 125 females and 125 males without voice complaints are described. Males have a larger volume range but the relative pitch increase per volume of 10 dB is equal for males and females.

The pitch increase is not linear by equal volume increase: at an increase from 60 to 70 dB there is less pitch increase than from 70 to 80 dB.

In chapter 7 the relationships between strong and weak voices are analysed.

The differences are significant. Strong voices have more tone and volume capacity and can switch on less pitch by speaking loudly. The weak voices have less vocal range and have to switch on more pitch to be able to amplify. A loudness of for instance 75 dB demands of a weak voice a sub-maximum effort, while a strong voice does not even work at half strength.

By improving voice techniques much attention is given to a low, relaxed voice. By transferring to speaking situations and practicing of the professional voice one should try to control the excessive pitch increase. This has been proven to be effective by the results of the voice measurement of the patients after therapy.

Even though this is only a symptomatic treatment of a weak voice, one cannot turn a weak voice into a strong voice.

The daily practice proves quite regularly that the patients voice capacity does not always increase, but that the patient learns how to use his capacities in a different way.

In chapter 8 the tone and volume performance of two groups of teachers are compared. 20 female teachers with voice complaints and 30 without complaints. The first group consisted of more people who had chosen the wrong profession regarding the voice. The second group were proven good voices because they had been teaching for 10 years without voice complaints. The voice performances show significant differences between both groups and the discrimination analyses shows that people with a speech volume range smaller than 30 dB and a pitch range smaller than 2 octaves (24 semi tones) are not suitable for teaching. Suitable voices for this profession are people who have a range of more than 40 dB and 2,5 octaves (30 semi tones).

In chapter 9 a beginning is made for a more systematical evaluation of vocal behaviour

and voice technique.

The inducer was a voice stress experiment for a group participants with a wrong resp. good vocal technique. The experiment could not proceed because of the judges of the voice technique (speech therapists) could not reach agreement about which test subjects belonged in which group. Then the judgement process became subject of investigation. A video registration was made of 12 selected subjects during different speech tasks. After that 15 and 51 speech therapists received the task to judge the voice technique of the subjects. The judgement was repeated after two weeks. Elementary differences became eminent like terminology and definitions like method, interpretation, difference in severity rating and internal standards. The reproducibility of the judgements was so weak that one could not speak of professionalism and that a systematical improvement of this perceptual evaluation should be set up.

It was the third revealing confrontation of subjective judgement with objectivation of perception and behaviour.

We thought to be able to point at laryngological, phonetic or voice behavioral factors to the capacity of the (speech) voice.

As far as the laryngological factors are concerned is closing and vibration form of the vocal folds important and a video-stroboscopic visualisation of the larynx during different vocalizations is necessary. But the registration and analysis and interpretation of these movements ask for further objectivation and examiner independent parameters need to be developed.

The chance of irregular and asymmetrical vibrations is certainly enlarged at voice pathology and the analysis and objectivation is still a technical problem. We keep on emphasizing that the vocal organ is more than vocal folds and that a laryngoscopy is good for a first morphological screening.

Concerning phonetic factors, it was known that phonetography gives indications of vocal capacity. Although the speaking voice will be a part of the phonetogram we find the phonetogram for the speaking voice too common.

We have looked for a differentiation in our measurements, for special performances and results of the voice while speaking. For many people the speaking voice is the only important thing and by measuring different speech tasks, specific characteristic features are uncovered.

The voice range, as measured by the phonetogram, remains an important indication for the vocal capacity. We also conclude that under influence of therapy and training the range sometimes extends but the speech complaints remain, or that the range sometimes remains identical, while the complaints lessen or disappear.

The way the voice is amplified, the extent of control of the speech tone, seem to be helpful clues for the capacity of the speech voice. Measuring sound achievements, - sometimes the singing voice, mostly the speaking voice- has to become more of a routine. Acoustical analyses have to take place systematically and the development of European/international standards must be worked out further. Technological and

electronic aids must be used more but the matching with a systematic comparison with standardized perceptual evaluation of the voice must surely not be neglected. A factor of voicing behaviour will always play a part no matter how important physiological and physical characteristics of the vocal tract are.

As far as vocal behavior is concerned we are placed opposite of an indistinct and not easy to grasp element of voice production. The voice is certainly defined by (un)conscious manner of vocal production. Describing (learned) behaviour, the phenomena of vocal abuse and the wrong way of vocal use illustrate how this investigation is mostly a behavioural science. The engineer even thinks that these aspects are measurable through acoustical analysis (eg. Soft Phonation Index). The speech therapist not only tries to describe the vocal behaviour but also tries to influence it.

By changing the vocal behaviour (and that is the essence of vocal therapy) one firstly wants to remediate the incorrect and tiring way of vocal use. If that is the most important complaint, the vocal quality will also change. But vocal behaviour is also a part of communication behaviour and therefor also is in relation to cognitive and emotional behavioural phenomena. It was determined that the voice is dependent on external factors, personal factors, overall stress, motivation and mood. Dysphonia is not a diagnosis, it is a symptom (Hirano, 1989).

SAMENVATTING EN CONCLUSIES

Een stemstoornis (dysfonie) zal vaak veroorzaakt worden door een afwijking van de stemplooiën. Een kleine afwijking kan al voor een opvallende stoornis zorgen en eenvoudige chirurgie kan dan wonderen doen. Bij sommige (ernstige) stemstoornissen is er geen laryngeale stoornis vast te stellen. Respiratoire of resonatorische factoren kunnen zeker de stemkwaliteit beïnvloeden. Medische behandeling of stemtechnische oefentherapie kunnen duidelijke verbetering voortbrengen, maar de verandering is doorgaans minder spectaculair en vraagt inzet en discipline van de patiënt. Er zijn ook stemklachten die worden veroorzaakt door het stemgebruik: de klacht ontstaat sluitend, is doorgaans ook ruimer dan stemkwaliteit omdat vermoeidheid en pijn meespelen en pas na enige tijd ervaart de persoon dat de klacht samenhangt met de hoeveelheid stemgebruik. Deze overmatige belasting van de stem verantwoordelijk stellen voor de klachten ligt dan voor de hand, maar is dit terecht?

Deze 'overmatige' belasting vraagt natuurlijk al langere tijd extra inspanning en wordt aanvankelijk normaal gevonden, maar later wordt dit stemgebruik beschouwd als oorzaak van de klachten en het vermoeidheidsgevoel. De grootte van die extra inspanning hangt af van de zwaarte van de gevraagde activiteit (stembelasting) en de mate waarin het vermogen beschikbaar is om die taak te volbrengen (stembelastbaarheid). De vaststelling dat zoveel patiënten hun stemklachten toeschrijven aan stembelasting was een verwondering en was aanleiding tot vele (onbeantwoorde) vragen.

Het doel van deze studie was meer inzicht te krijgen in de rol van stemgebruik, in de mechanismen van stembelasting en stembelastbaarheid, in de normatieve gegevens van stemgebruik om zodoende onderbouwde uitspraken te kunnen doen over geschiktheid, ongeschiktheid of restcapaciteit van iemands spreekstem.

In hoofdstuk 2 wordt een (literatuur) overzicht gegeven van het stemgebruik in relatie tot arbeid (beroepsdysphonie). Ergonomische studies van het spreken tijdens de beroepsuitoefening zijn schaars en meestal gericht op geselecteerde onderdelen zoals bv. vochtigheidsgraad of invloed van ruis en lawaai. Vooralsnog is er weinig bewezen over de invloed van de werkomstandigheden op de stem en deze studies zijn dan ook nog vaak tot stand gekomen onder laboratorium condities.

Het gevolg van de stembelasting voor de stem krijgt pas recent aandacht. De stembelastingsindex van het spreken geeft vooral gewicht aan de luidheid. De gevraagde stemkwaliteit en de inhoud van de boodschap zullen ook wel belangrijk zijn maar zijn vooralsnog niet weergegeven in de formule.

In de epidemiologie van beroepsziekten worden stemklachten slechts zelden vermeld en dit heeft twee redenen: ten eerste omdat er geregistreerd wordt op ziekte en niet op beperking en ten tweede omdat mensen met beroepsdysfonie slechts een minuscule groep zijn in vergelijking met de hoeveelheden mensen met arbeidsongeschiktheid wegens rugklachten, respiratoire klachten of psychiatrische stoornis. Een gevolg hiervan is dat beroepsdysfonie geen aandacht en geen prioriteit heeft en dat er zelfs geen definitie van gevonden kan worden. Het onderscheid met een verkeerde beroeps-

keuze is belangrijk en essentieel is dat de aanvankelijk toereikende stem wordt vermindert door de beroepsuitoefening. Zal iemand met een aanvankelijk toereikende stem stembandknobbeltjes krijgen door flink stemgebruik? Er zijn geen studies die dit directe verband aantonen maar het is een ervaringsfeit dat veel problemen zouden voorkomen worden indien vooraf de stemprestaties zouden gedocumenteerd worden. Hedendendage gebeurt de onderzoeksmethodologie nog vaak 'schattenderwijs' en de volgende hoofdstukken geven aan dat objectieve metingen van stemprestaties en registraties op de werkplek mogelijk zijn.

In hoofdstuk 3 wordt ingegaan op de kwantificering van het stemgebruik zelf: registratie van volume en duur van het spreken in de natuurlijke arbeidssituatie is mogelijk dankzij de stemaccumulator.

De ontwikkeling van de stemaccumulator bevestigde nogmaals dat het meten van stemproductie talrijke valkuilen heeft, maar dat het toch mogelijk is de stemeisen van een beroepsgroep of een specifieke situatie te documenteren. Van beroepsgroepen met verschillende stembelasting werden telkens bij een zestal personen stemaccumulatiemetingen geregistreerd en geanalyseerd. Het resultaat van deze metingen was voor alle partijen ietwat verbazend: zeker de proefpersonen maar ook de onderzoekers hadden verwacht dat het stemgebruik groter zou zijn. Het nauwkeurig bepalen van de stemberoepsvaardigheid is een voorwaarde om vervolgens uitspraken te kunnen doen over iemands (on)mogelijkheden om dit te kunnen volbrengen. Dat deze kwantificering zinvol is, blijkt ook uit de vaststelling dat de subjectieve schatting toch anders was dan de objectieve meting.

In hoofdstuk 4 wordt aandacht geschonken aan een eerste aspect van stembelastbaarheid nl. het onderzoek van de larynxfunctie. Toen waren we nog in de veronderstelling dat electroglottografie een toereikende niet-invasieve onderzoeksmethode van de stemplooifunctie was, mits maar een goede analysetechniek van het EGG signaal ontwikkeld werd. Zelfs bij een gestandaardiseerd stemgeluid was de reproduceerbaarheid onvoldoende. De electroglottograaf is goedkoop, het signaal is zeer eenvoudig maar het is slechts bruikbaar als meting van de grondtoon en enkele kwalitatieve analyses zoals registerovergangen en steminzet. Het EGG signaal zegt iets over de mate van stembandcontact maar de glottissluiting (opening) kan er niet nauwkeurig mee gepreciseerd worden: kwantitatieve maten zoals nu door sommige commerciële apparaten berekend worden, moeten met grote voorzichtigheid geïnterpreteerd worden. Electroglottografie kan alleen gebruikt worden in combinatie met andere instrumenten en met signaalanalyses. Er zijn aanwijzingen dat het EGG signaal wel overeenkomsten heeft met de jitter analyses van het akoestisch signaal maar niet met de shimmer waarden van het stemgeluid.

Hoofdstuk 5 is besteed aan inspanningsproeven van de stem. Bij eerdere ervaringen met stembelastingstests waren reeds vragen gerezen met betrekking tot de waarde hiervan. In de Stem Interval Test is het stemgebruik al flink opgedreven en dit wordt

toegepast bij 20 patiënten met stemvermoeidheidsklachten en bij een controlegroep (n=12) zonder stemklachten. De test wordt geïsoleerd uitgevoerd en in combinatie met een werkdag. Telkens gebeurt electroglottografische analyse en akoestische analyse en wordt een pijn- en vermoeidheidsschaal afgenomen. Aan de hand van deze parameters konden geen significante verschillen worden vastgesteld tussen beide groepen. De klinische betekenis van stembelastingsproeven kan hiermee zeker in vraag gesteld worden. Het geeft ook aan dat stemvermoeidheid iets meer of iets anders is dan vocale of laryngeale vermoeidheid. Stemvermoeidheid is een complex symptoom van interne en externe factoren, van motivatie en waardering, van gedrag en attitude, van arbeidsbelasting en van persoonlijke belasting, van gebrek aan empathie of onbegrip... Ten tweede maal stellen wij vast dat subjectieve klachten niet bevestigd worden door (deze) objectieve metingen.

In hoofdstuk 6 en 7 is nader onderzoek gedaan naar de samenhang tussen luider spreken en hoger spreken. In de stempedagogie is het een ervaringsgegeven dat goede stemmen bij luider spreken niet of nauwelijks in toonhoogte stijgen. In de stemtherapie is bekend dat patiënten bij luider spreken meestal teveel in toonhoogte stijgen. Deze gegevens zijn ook herkenbaar in het fonetogram zeker wanneer de spreekstem betrokken wordt bij de afname.

In hoofdstuk 6 zijn de resultaten beschreven van 125 vrouwen en 125 mannen zonder stemklachten. Mannen hebben wel een grotere volume range maar de relatieve toonhoogtestijging per volumetoename van 10 dB is gelijk voor mannen en vrouwen. De toonhoogtestijging is ook niet lineair bij gelijke volumetoeenames: bij een versterking van 60 naar 70 dB is er minder toonhoogtestijging dan van 70 naar 80 dB.

In hoofdstuk 7 worden deze relaties bij sterke en bij zwakke stemmen geanalyseerd. De verschillen zijn significant: sterke stemmen hebben meer toon- en volumecapaciteit en hoeven bij luider spreken minder toonhoogte in te schakelen, de zwakke stemmen hebben minder bereik en moeten meer toonhoogte inzetten om te (kunnen) versterken. Een luidheid van bv. 75 dB eist van een zwakke stem bijna een submaximale inspanning terwijl een sterke stem nog niet op halve kracht werkt.

Bij verbetering van de stemtechniek wordt veel aandacht geschonken aan een lage en ontspannen stemgeving. Bij transfer naar de spreesituaties en oefenen van de beroepstem zal men trachten de (overmatige) toonhoogtestijging onder controle te houden. Dat dit effectief is, bewijzen de resultaten van de stemmetingen van de patiënten na therapie. Alhoewel dit maar een "symptomatische" behandeling is -van een zwakke stem kan men geen sterke stem maken- bewijst de dagelijkse praktijk ook regelmatig dat de stemcapaciteit van de patiënt niet altijd uitbreidt maar dat de patiënt leert zijn mogelijkheden anders te gebruiken.

In hoofdstuk 8 worden de toon en volumeprestaties tijdens spreken van twee groepen leerkrachten vergeleken: 20 leraressen met stemklachten en 30 leraressen zonder stemklachten. De eerste groep bevatte meerdere mensen met een verkeerde beroepskeuze wat betreft stem, de tweede groep waren bewezen goede stemmen omdat ze al

langer dan tien jaar onderwijs gaven zonder stemklachten. De stemprestaties tonen significante verschillen tussen beide groepen en de discriminantanalyse toont dat mensen met een spreekvolume range kleiner dan 30 dB en een toonbereik kleiner dan 2 oktaven (24 semitonen) niet geschikt zijn voor lesopdrachten; personen waarbij dit meer bedraagt dan 40 dB en 2,5 oktaven (30semitonen) hebben een geschikte stem voor deze arbeid.

In hoofdstuk 9 wordt een begin gemaakt met een systematischer beoordeling van stemgedrag en stemtechniek. De aanleiding was een stembelastingsexperiment voor een groep deelnemers met een verkeerde resp. goede stemtechniek. Het experiment kon als dusdanig niet doorgaan omdat de beoordelaars van de stemtechniek (logopedisten) niet voldoende overeenstemming bereikten over welke proefpersonen in welke groep thuishoorden. Toen werd het beoordelingsproces onderwerp van onderzoek. Bij 12 geselecteerde proefpersonen met goede en verkeerde stemtechniek werd een video-registratie gemaakt tijdens verschillende spreekopdrachten. Daarna kregen 15 en 51 logopedisten de opdracht de stemtechniek van de proefpersonen te beoordelen; twee weken later werd de beoordeling herhaald. Hierbij kwamen elementaire verschillen aan de oppervlakte zowel wat betreft terminologie en definitie als methode, interpretatie, verschillende ernstschaling en interne standaarden. De reproduceerbaarheid van de beoordelingen was zo zwak dat van professionaliteit haast geen sprake was en dat een systematische verbetering van deze perceptuele beoordeling dient opgezet. Het was de derde openbare confrontatie van subjectieve oordelen met objectivering van waarneming en gedrag.

Bij dit onderzoek dachten we laryngologische, fonatorische of stemgedragsfactoren te kunnen aanwijzen voor de belastbaarheid van de spreekstem.

Wat betreft laryngologische factoren is sluiting en trillingsvorm van de stemplooiën zeker belangrijk en videostroboscopische visualisering van de larynx tijdens verschillende stemgevingen is noodzakelijk. Maar de registratie, analyse en de interpretatie van deze bewegingen vragen nog nadere objectivering en onderzoeker onafhankelijke parameters moeten worden ontwikkeld. Zeker bij stempathologie is de kans op onregelmatige en asymmetrische trilling vergroot en de analyse en objectivering hiervan is nog een (technisch) probleem. Tevens blijven we benadrukken dat het stemorgaan meer is dan de stemplooiën en dat een laryngoscopie enkel goed is voor een eerste morfologische screening.

Wat betreft fonatorische factoren was bekend dat het fonetogram aanduidingen geeft van de belastbaarheid. Alhoewel de spreekstem deel zal uitmaken van het fonetogram, vinden wij het fonetogram voor de spreekstem toch te algemeen. Met onze metingen hebben we gezocht naar een verbijzondering, naar specifieke prestaties en resultaten van de stem bij het spreken. Voor veel mensen is alleen de spreekstem belangrijk en door metingen te doen bij verschillende spreekopdrachten werden specifieke kenmerken blootgelegd. De stemomvang, zoals gemeten bij het fonetogram, blijft zeker een

belangrijke indicatie van de stembelastbaarheid. Maar ook wordt vastgesteld dat onder invloed van therapie of training de omvang soms uitbreidt maar de klachten bij spreken toch blijven, of dat de omvang soms identiek blijft terwijl de klachten verminderen of verdwijnen. De manier waarop de stem versterkt wordt, de mate waarin de spreektoon wordt beheerst blijken dan nuttige aanwijzingen te zijn van belastbaarheid van de spreekstem. Het meten van de geluidsprestaties -soms de zangstem, meestal de spreekstem- moet meer routine worden. Akoestische analyses moeten systematisch plaatsvinden en de ontwikkeling van Europese/internationale standaarden moeten verder worden uitgewerkt. Technologische en elektronische hulpmiddelen moeten meer intrede doen, maar de koppeling aan en systematische vergelijking met gestandaardiseerde perceptuele beoordelingen van het stemgeluid mag daarbij zeker niet verwaarloosd worden. Hoe belangrijk fysiologische en fysische kenmerken van de vocal tract ook zijn, er blijft een factor stemgevingsgedrag meespelen.

Wat betreft het stemgedrag worden we geplaagd tegenover een onduidelijk en niet eenvoudig grijpbaar element in de stemvorming. De stem wordt zeker bepaald door (on)bewuste wijze van stemproductie. Het beschrijven van (geleerd) gedrag, het verschijnsel stemmisbruik en verkeerd stemgebruik illustreren hoe dit onderzoeken ook vooral een toegepaste gedragswetenschap is. De ingenieur denkt zelfs dat deze aspecten meetbaar zijn via akoestische analyse (bv. Soft Phonation Index). De logopedist probeert dat stemgedrag niet alleen te beschrijven maar ook te beïnvloeden. Door het stemgedrag te veranderen -dat is in essentie toch stemtherapie- wil men in de eerste plaats de verkeerde en vermoeiende wijze van stemvorming remediëren. Als dat de belangrijkste oorzaak is van de klacht, zal ook nog vaak de stemkwaliteit verbeteren. Maar stemgedrag is ook een onderdeel van communicatiegedrag en staat dus ook in relatie tot cognitieve en emotionele gedragsverschijnselen. Er werd vastgesteld dat de stem ook afhankelijk is van externe factoren, van persoonlijke factoren, van algemene belastbaarheid, van motivatie en van "stemming". Dysphonia is not a diagnosis, it is a symptom (Hirano, 1989).

RÉSUMÉ ET CONCLUSIONS

A l'origine d'une dysphonie se trouve souvent une anomalie des plis vocaux. Même une microanomalie peut causer un désordre considérable. Dans ce cas-là, une simple intervention chirurgicale peut faire des miracles.

Dans certains cas de dysphonies graves, on ne constate aucun trouble laryngé. Des facteurs résonatoires ou respiratoires peuvent certainement influencer la qualité de la voix. Sans aucun doute, un traitement médical ou une thérapie de rééducation orthophonique peuvent améliorer considérablement la voix du patient. Toutefois, cette amélioration est en général peu spectaculaire et exige du patient motivation et discipline.

Il y a aussi des troubles vocaux liés à la manière dont la voix est utilisée. Ce trouble apparaît sournoisement, et généralement, il ne relève pas uniquement du domaine de la qualité de la voix du fait que fatigue et douleur interviennent. Ce n'est qu'après un certain temps que le patient fait le lien entre ce trouble et son utilisation vocale.

Il semble donc évident de rendre ce surmenage vocal responsable de ces troubles. Mais, cette attitude est-elle correcte?

Bien évidemment, ce surmenage vocal exige depuis quelque temps des efforts supplémentaires. Au début, on fait ces efforts sans vraiment y réfléchir, mais par la suite on considère l'utilisation qui est faite de la voix comme responsable des troubles et de la sensation de fatigue. L'importance de cet effort supplémentaire dépend de l'ampleur de l'activité exigée (la charge vocale) mais aussi de la mesure dans laquelle la capacité d'accomplir cette tâche est présente (la capacité de charger cette voix).

Constater que beaucoup de patients attribuent leurs plaintes à la charge vocale, nous a étonnés et a fait naître beaucoup de questions ratées sans réponse.

Le but de cette étude a été de voir plus clair dans le rôle des habitudes vocales, dans les mécanismes de la charge vocale, et de la capacité à supporter ces charges, dans les données normatives des habitudes vocales afin de savoir expliquer certains problèmes concernant l'aptitude, l'inaptitude ou la capacité résiduelle de la voix parlée.

Dans le deuxième chapitre nous donnons une bibliographie sur les malmenages vocales en rapport avec le travail (désordres vocaux professionnels).

Des études ergonomiques des performances vocales pendant le travail sont rares.

En plus, on vise souvent des sous-facteurs précis comme l'humidité relative ou bien l'influence des bruits.

Jusqu'à présent, on a prouvé peu de choses concernant l'influence des conditions de travail sur la voix. Il faut ajouter encore que ces études sont souvent faites au sein d'un laboratoire donc dans des conditions particulières.

Ce n'est que tout récemment, qu'on a prêté attention à l'impact de la charge vocale sur la voix elle-même. Les index de charge vocale de l'acte vocal confèrent surtout de l'importance à l'intensité. La qualité de la voix exigée et le contenu du message auront aussi leur importance, mais ne sont pas encore rendus dans la formule.

Dans l'épidémiologie des maladies professionnelles on ne mentionne que très rarement

des plaintes vocales. Ce phénomène a deux causes: tout d'abord parce qu'on enregistre des cas de maladies et non des cas de restriction de certaines capacités. La deuxième cause est le fait que les personnes souffrant d'une dysphonie professionnelle ne constituent qu'une minorité si on les compare aux nombreuses personnes en incapacité de travail due à des maux de dos, des problèmes respiratoires ou des désordres psychiatriques.

Par conséquent, la dysphonie professionnelle reste peu étudiée et n'est pas considérée comme prioritaire. On peut même dire qu'il est impossible de trouver une définition. La distinction avec un choix de métier erroné est importante, et essentiel est le fait qu'une voix qui, au début est efficace, perd de son efficacité à cause du métier exercé.

Est-ce que quelqu'un qui dispose initialement d'une voix suffisante développera par la suite des nodules des cordes vocales, parce qu'il utilise souvent sa voix? Il n'y a aucune étude qui démontre un lien direct entre ces deux faits, mais l'expérience prouve qu'on pourrait bien éviter de nombreuses pathologies si au préalable, on se documentait sur les prestations vocales.

Aujourd'hui la méthodologie de recherche recourt encore beaucoup aux évaluations globales et approximatives. Les prochains chapitres montrent que les études objectives des performances vocales et les enregistrements sur le lieu de travail sont possibles.

Dans le troisième chapitre nous parlons de la quantification des utilisations vocales même: l'accumulateur de la voix permet d'enregistrer le volume et la durée de l'activité orale dans la situation professionnelle normale. Le développement de cet accumulateur a encore confirmé que la mesure de la production vocale présente de nombreux pièges, mais qu'il est tout de même possible d'avoir des informations sur les exigences vocales d'un groupe professionnel ou d'une situation spécifique. Parmi des groupes professionnels présentant une charge vocale différente, on a choisi six personnes dont on a enregistré et analysé les mesures d'accumulation vocale. Le résultat de ces épreuves a quelque peu étonné toutes les parties concernées: en effet, les individus testés mais aussi les chercheurs avaient pensé que les utilisations vocales auraient été plus larges. Stipuler minutieusement la capacité professionnelle vocale d'une personne est une condition pour pouvoir par la suite formuler des remarques sur les compétences ou les incompétences de cet individu à accomplir cette activité orale. Constater que l'estimation subjective a été différente de l'estimation objective, montre que cette quantification a beaucoup de sens.

Dans le quatrième chapitre nous abordons un premier aspect de la capacité de charger la voix, notamment l'étude de la fonction laryngée. A l'époque nous supposions encore toujours que l'électroglottographie était une méthode non invasive et suffisante pour l'analyse de la fonction des plis vocaux, pourvu qu'on élabore une bonne technique d'analyse du signal électroglottographique (EGG). Même avec un son vocal standardisé la capacité de reproduction n'a pas été suffisante. L'électroglottographe ne coûte pas cher et le signal est très simple, mais on ne peut s'en servir que pour mesurer la fréquence fondamentale et pour faire quelques analyses qualitatives comme l'intonation et

les modifications de tessiture. Le signal électroglottographique donne des indications sur la mesure de contact des cordes vocales mais cette théorie ne permet néanmoins pas de préciser la fermeture glottique de façon exacte: il faut interpréter les résultats quantitatifs calculés actuellement par certains appareils commerciaux avec beaucoup de prudence.

On ne peut employer la technique de l'électroglottographie qu'en combinaison avec d'autres instruments et avec d'autres analyses de signaux. Il y a des indications selon lesquelles le signal électroglottographique présente des analogies avec les analyses de perturbation fréquentielle du signal acoustique, et non avec les valeurs de perturbation d'amplitude du son vocal.

Le cinquième chapitre est consacré aux épreuves d'effort de la voix. Certaines expériences portant sur des tests de charge vocale ont déjà fait naître des questions quant à leur valeur. Dans le *Test Intermittence de la Voix* on a déjà fait monter l'effort de la voix. On applique cette méthode à 20 patients se plaignant de fatigue vocale et à un groupe de contrôle (N=12) n'émittant pas de plaintes. On fait le test pendant un jour de congé et lors d'un jour de travail. A chaque reprise on fait l'analyse électroglottographique et acoustique, et on établit une échelle de douleur et de fatigue. A l'aide de ces paramètres il a été impossible de constater des différences significatives entre les deux groupes. Cette conclusion peut certainement mettre en question l'importance clinique des tests de charge vocale.

Cela révèle aussi que la fatigue de la voix est un problème plus large ou bien tout différent de la fatigue laryngée. La fatigue de la voix est un symptôme complexe de facteurs internes et externes, de motivation et d'appréciation, de comportement et d'attitude, de charge professionnelle et de charge personnelle, d'un manque d'empathie ou de compréhension...

De nouveau nous constatons que ces mesures faites en toute objectivité, ne peuvent pas confirmer les plaintes subjectives.

Dans le sixième et septième chapitre nous avons examiné de plus près le rapport entre parler plus fort et parler plus haut. La pédagogie vocale est de l'avis que quand on parle plus fort, les bonnes voix ne montent presque pas, ou ne montent pas du tout. Il est bien connu en matière de la rééducation orthophonique que les patients qui parlent plus fort, montent aussi trop la voix. On retrouve ces données dans le phonétogramme, surtout quand la voix parlée est prise en considération lors du mesurage.

Le sixième chapitre donne les résultats de 125 femmes et de 125 hommes ne présentant aucun trouble vocal. Les hommes ont bien sûr plus de volume, mais la hausse relative de la fréquence du son par augmentation d'intensité de 10 dB est la même pour les hommes et pour les femmes. La hausse de la fréquence n'est pas non plus linéaire dans les cas d'augmentations d'intensité identique: avec une augmentation de 60 à 70 dB il y a une hausse de fréquence inférieure à celle du passage de 70 à 80 dB.

Dans le septième chapitre on analyse ces rapports pour les voix fortes et les voix faibles. Les différences sont significatives: les voix fortes ont plus de capacité de

fréquence et d'intensité et quand il faut parler plus fort, ces voix-ci doivent employer moins de hauteur, tandis que les voix faibles ont une portée inférieure et doivent employer une fréquence plus élevée afin de pouvoir amplifier. Ainsi une intensité de 75 dB exige presque un effort submaximal d'une voix faible, tandis qu'une voix forte n'emploie même pas la moitié de sa capacité. Pour améliorer la technique vocale, il faut accorder beaucoup d'attention à une production vocale basse et décontractée. En cas de transfert à la voix conversationnelle et à la voix professionnelle, on va tenter de maintenir sous contrôle l'augmentation de la fréquence. Les résultats des mesurages des voix des patients après la thérapie montrent l'efficacité de cette technique. Bien que ce traitement soit seulement 'symptomatique' -il est impossible de transformer une voix faible en une voix forte- la pratique prouve aussi régulièrement que la capacité vocale du patient n'amplifie pas toujours, mais que le patient apprend comment employer ses capacités d'une autre manière.

Dans le huitième chapitre nous faisons une comparaison entre la fréquence et l'intensité de la voix parlée de deux groupes d'enseignantes lorsqu'elles parlent: d'une part, 20 présentent des plaintes vocales, de l'autre 30 n'en ont pas. Le premier groupe contenait plusieurs personnes qui, au niveau de la voix, avaient fait un choix professionnel erroné. Les femmes du deuxième groupe avaient de bonnes voix confirmées parce qu'elles enseignaient déjà depuis plus de dix ans sans jamais se plaindre de leur voix. Les performances vocales révèlent des différences importantes entre les deux groupes. L'analyse discriminatoire montre que les personnes ayant une intensité inférieure à 30 dB et un champ de fréquence inférieur à deux octaves (24 semitons) ne sont pas aptes pour des tâches pédagogiques. Les personnes chez qui ceci est supérieur à 40 dB et 2,5 octaves (30 semitons) ont une voix apte à l'enseignement.

Dans le neuvième chapitre on entame un bilan plus systématique des comportement et technique vocaux. La cause en était une expérience de charge vocale pour un groupe de sujets ayant respectivement une mauvaise et une bonne technique vocale. L'expérience ne fut être poursuivie en tant que telle parce que les appréciateurs de la technique vocale (les logopèdes) ne pouvaient pas se mettre d'accord sur la répartition des sujets dans les groupes à analyser.

Ce fut alors l'appréciation qui devient le sujet de l'étude: on a fait un enregistrement vidéo des 12 sujets ayant une bonne ou une mauvaise technique vocale pendant les différentes situations conversationnelles. Ensuite, 15 et 51 logopèdes ont dû apprécier leur technique vocale. Deux semaines plus tard, on a répété cette appréciation.

Cette expérience a révélé des différences élémentaires en ce qui concerne e.a. la terminologie, la définition, la méthode, l'interprétation, les gradations de la gravité de l'état d'un patient, et les critères internes. Il a été pratiquement impossible de reproduire les appréciations de sorte qu'on pouvait difficilement parler de professionnalisme. Il faut donc conclure qu'une amélioration systématique de cette appréciation perceptuelle est indispensable. Celle-ci était la troisième confrontation frappante entre les appréciations subjectives et l'objectivation de l'observation.

Dans cette recherche, nous avons cru pouvoir relever des facteurs laryngologiques, phonatoires ou bien des facteurs de comportements vocaux relatifs à la capacité de charge de la voix parlée.

En ce qui concerne les facteurs laryngologiques, la fermeture et la forme de vibration des plis vocaux sont certainement importantes et la visualisation vidéostroboscopique du larynx pendant les différentes émissions vocales est nécessaire.

Toutefois, l'enregistrement vidéo, l'analyse et l'interprétation de ces vibrations exigent une objectivation plus grande. Il faut également développer des paramètres indépendants à l'expérimenteur. En effet, dans le cas de la pathologie vocale le risque de vibration irrégulière et asymétrique est plus grand et l'analyse et l'objectivation de celle-ci restent un problème technique. Nous continuons également à souligner que le tractus vocal ne se résume pas à des plis vocaux et qu'une laryngoscopie est uniquement utile quand on fait un premier examen morphologique.

Quant aux facteurs phonatoires, on savait que le phonétogramme donne des indications quant à la capacité de charge vocale. Bien que la voix parlée soit recueillie dans le phonétogramme, nous estimons que celui-ci est trop général pour la voix parlée.

Pendant les expériences faites, nous avons recherché les cas particuliers, les prestations spécifiques et les résultats de la voix parlée. Pour beaucoup de personnes la voix parlée seule est importante et en la mesurant pendant plusieurs situations simulées, on a découvert des caractéristiques spécifiques. L'ampleur de la voix, mesurée à l'aide du phonétogramme, reste certainement une indication importante de la capacité de charge de la voix. Mais on constate également que sous l'influence de thérapie ou d'entraînement, cette ampleur peut devenir plus grande. Toutefois, lorsqu'on parle, les plaintes subsistent.

Il est également possible que l'ampleur reste invariable tandis que les plaintes diminuent ou disparaissent. La façon dont la voix s'amplifie, la mesure avec laquelle la tonalité de la voix parlée est maîtrisée, semblent alors être des indications utiles de la capacité de charge de la voix parlée. Quand on mesure les performances phonatoires -parfois la voix chantée, la plupart du temps la voix parlée- cela doit devenir plus une routine.

Des analyses acoustiques doivent avoir lieu de façon systématique et le développement des critères européens et internationaux doit être poursuivi. Il est vraiment indispensable d'obtenir plus d'aide technologique et électronique, mais on ne peut surtout pas oublier de combiner et de comparer systématiquement ces techniques aux appréciations perceptuelles standardisées de la production vocale.

Aussi importantes que les caractéristiques physiologiques et physiques de la cavité nasopharyngienne soient, il reste cependant le facteur du comportement vocal en jeu.

En ce qui concerne ces habitudes vocales, nous faisons face à un élément obscur et non facilement saisissable de la production vocale. La voix est certainement déterminée par une façon (in)consciente de production vocale. La description de comportement intelligent, le phénomène d'utilisation abusive de la voix illustre comment ces

recherches entrent dans une science de comportement appliquée. L'ingénieur croit même que ces aspects sont mesurables via une analyse acoustique (p.ex. *Soft Phonation Index*). Le logopède essaie non seulement de décrire ces habitudes vocales, mais tente également de les influencer. En changeant les habitudes vocales, -ce qui bien sûr est l'essence de la thérapie de la voix- on veut d'abord remédier à la façon fautive et fatigante de la production vocale. Si ceci est la cause principale de la plainte, la qualité de la voix sera aussi améliorée dans beaucoup de cas. Mais les habitudes vocales font également partie du comportement communicatif et entrent donc également en relation avec les phénomènes de conduite cognitives et émotionnelles. On a constaté que la voix dépend également de facteurs externes, de facteurs personnels, de capacité de charge générale, de motivation et de 'humeur'. *La dysphonie n'est pas un diagnostic, c'est un symptôme* (HIRANO, 1989).

DANKWOORD

Na jaren hard werken is het 'boekje' dan toch klaar geraakt. Het onderwerp is een langzaam rijpend proces geweest dat groeide met de ervaringen van regelmatige vragen en terugkerende problemen. Als je dan komt uit een opleiding die als universitaire studierichting onbekend is en volgens sommigen zelfs overbodig is, ligt het niet zo voor de hand dat je ook nog een wetenschappelijke dissertatie maakt. Maar tal van mensen en collegae hebben me aangemoedigd en geholpen, hebben middelen ter beschikking gesteld en dingen voor mij uitgezocht of taken van mij overgenomen. Het afgelopen jaar moest ik soms egocentrisch zijn om dit werk te kunnen afronden, daarom ik heb er ook niet de minste moeite mee om toe te geven dat deze dissertatie resultaat is van teamwerk.

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CURRICULUM VITAE

De auteur werd geboren op 8 maart 1948 te Hasselt. Na de lagere school te Schulen studeerde hij in 1966 af aan de Latijns Griekse Humaniora van het Damiaancollege te Aarschot.

In 1970 behaalde hij het diploma van Gegradueerde in de Logopedie en Audiologie aan het Hoger Technisch Instituut te Brugge; Na enkele jaren werkzaam te zijn geweest als logopedist bij Neurologie en Traumatologie van het Revalidatiecentrum te Hoensbroek, gaat hij in 1974 naar Leuven om aan de Katholieke Universiteit orthopedagogie of logopedie te studeren. Het werd toch logopedie: in 1977 werd de studie afgerond, in 1979 werd de eindverhandeling over Fonetografie onder leiding van Professor Damste afgeleverd en verkreeg hij met onderscheiding het diploma van Licentiaat in de Logopedie en Audiologie.

Inmiddels was hij reeds gestart als docent aan de Opleiding Logopedie van de Hogeschool Heerlen en de Leergangen Speciaal Onderwijs te Tilburg. In 1981 werd hij diensthoofd van de polikliniek Logopedie van het Revalidatiecentrum te Hoensbroek hetgeen later ontwikkelde tot het Logopedisch Centrum, het eerste niet-academische centrum waar meerdere disciplines betrokken waren bij de diagnostiek en therapie van spreekstoornissen.

Toen even later de vakgroep KNO van de Rijksuniversiteit Limburg ontstond werd hij part time gedetacheerd in Maastricht om zodoende de academisering van het Logopedisch Centrum te bereiken. Toen dit in 1989 onhaalbaar bleek kwam hij halftime bij KNO in het Academisch Ziekenhuis Maastricht voor medewerking in het Foniatrie spreekuur en werd geleidelijk het onderzoekproject Fonometrie opgestart. Sinds 1993 wordt de andere halftime ingevuld bij het Audiologisch Centrum Hoensbroeck met als taken communicatietraining bij volwassen slechthorenden en in toenemende mate diagnostiek van kinderen met communicatieve ontwikkelingsstoornissen.

Over de diagnostiek van gestoorde stem en taalverwerving publiceerde hij tal van artikels en gaf hij voordrachten in binnen en buitenland en op internationale congressen. Hij is lid van verschillende internationale organisaties en commissies in Nederland en in Vlaanderen, docent in Nascholingscursussen van meerdere Hogescholen en Universiteiten en (mede)organisator van de tweejaarlijkse nascholingscursus Kliniek van Stemstoornissen voor KNO-artsen.

De auteur is gehuwd en vader van vier dochters. Er is te weinig tijd voor sport, muziek en politiek maar een van zijn eerste publicaties -getiteld 'Kiezen of Delen'- argumenteerde al dat logopedisten veel meer moesten specialiseren in plaats van te generaliseren.