Helsinki University of Technology Laboratory of Acoustics and Audio Signal Processing
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OCCUPATIONAL VOICE - STUDYING VOICE PRODUCTION AND PREVENTING VOICE PROBLEMS WITH SPECIAL EMPHASIS ON CALL-CENTRE EMPLOYEES

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OCCUPATIONAL VOICE - STUDYING VOICE PRODUCTION AND PREVENTING VOICE PROBLEMS WITH SPECIAL EMPHASIS ON CALL-CENTRE EMPLOYEES

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ABSTRACT OF DOCTORAL DISSERTATION

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Name of the dissertation

Occupational voice - Studying voice production and preventing voice problems with special emphasis on call-centre employees.

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Laboratory Acoustics and Audio Signal Processing
Field of research Speech acoustics, Occupational voice research
Opponent(s) Docent Stellan Hertegård, Karolinska University Hospital Huddinge, Stockholm, Sweden
Supervisor Professor Paavo Alku

Abstract

This thesis deals with the occupational voice. In modern society, there is an increasing demand for oral communication in many professions. The label ‘occupational voice’ refers to those occupations where voice is the major tool. Employees in these occupations often suffer from voice symptoms to varying extents. In this thesis, the telephone customer service advisors are the target group of professional voice users. Telephone services constitute an example of expanding modern-day speech-related professional contexts. On the telephone, the speaker must rely solely on his/her voice without support from body language or written communication. Originally, initiation to gather data to be studied in this thesis came from the largest Finnish telecommunications operator Sonera (currently known as TeliaSonera Finland Oyj) in an effort to gain knowledge about the voice of their call-centre personnel.

The first goal of this thesis was to investigate to what extent call-centre customer service advisors experience voice problems. The study showed that prolonged voice use can result in vocal symptoms even in the case of good environmental factors. Secondly, the aim was to find out how call-centre customer service advisors benefit from voice training. It was found that preventative voice training constitutes an efficient method to decrease voice symptoms.

The third goal was to investigate how changes in voice production during a working day could be measured objectively using information embedded in the acoustic speech signal. Parameters were extracted both directly from the speech pressure signals and the glottal flows estimated by inverse filtering (IF). Only the fundamental frequency showed a statistically significant change during the working day. A possible explanation for the minor acoustical changes might be a good acoustical environment which did not make the employees raise their voice level. However, it was found that extracting acoustical parameters from running speech recorded in realistic work environments and communication situations is a prospective method to study voice production. To the best of the author’s knowledge, this was also the first time when continuous natural speech collected in a realistic occupational environment was used for IF. In addition, comparison between two IF methods showed consistent results hence encouraging IF to be a promising tool in the future research of occupational voice.

Keywords occupational voice, telephone work, voice training, acoustic voice analysis, inverse filtering

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VÄITÖSKIRJAN TIIVISTELMÄ

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Ääni työvälineenä – Äänentuoton tutkiminen ja ääniongelmien ennaltaehkäiseminen, kohderyhmänä puhelimessa työskentelevä asiakaspalveluhenkilöstö.

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Työn valvoja Professori Paavo Alku

Tiivistelmä

Tämän väitöskirjan aiheena on puheääni ja sen kestävyys työvälineenä. Nykypäivän yhteiskunnassa puhekommunikaation määrä lisääntyy jatkuvasti, ja monessa työssä puheääni on sekä ensisijainen että välttämätön työväline. Ammatikseen ääntä käyttävät henkilöt kokevat äänen oireita vaihtelevassa määrin. Tässä väitöskirjatyössä kohderyhmänä ovat puhelimessa työskentelevät asiakaspalvelutoimihenkilöt, jotka edustavat kasvavaa toimialaa. Puhelintyön erityispiirre on se, ettei puhuja voi tukeutua elekieleensä tai kirjalliseen materiaaliin. Aloite puhelintyöntekijöiden tutkimiseen tuli alun perin teleoperaattori Soneralta (nykyisin TeliaSonera Finland Oyj) yrityksen halutessa laajentaa tietojaan puhelinhenkilöstön hyvinvoinnista.

Tutkimuksen ensimmäinen tavoite oli selvittää, kuinka paljon puhelimessa työskentelevät asiakaspalvelutoimihenkilöt kokevat ääniongelmia. Tulokset osoittivat, että äänen käyttö työvälineenä voi johtaa äänioireisiin, vaikka työpaikan olosuhteet olisivat äänenkäytön kannalta hyvät. Tutkimuksen toisena tavoitteena oli selvittää, kokevatko puhelimessa työskentelevät asiakaspalvelutoimihenkilöt ennaltaehkäisevän äänikoulutuksen hyödylliseksi. Koulutus todettiin hyödylliseksi, ja se vähensi työntekijöiden kokemia äänioireita.

Tutkimuksen kolmantena tavoitteena oli selvittää, miten työpäivän aikaiset muutokset äänen tuotossa voidaan objektiivisesti mitata akustisesta puhesignaalista. Mittauksia tehtiin sekä puhesignaalin paineaallosta että käänteissuodatuksella estimoidusta glottis-herätteestä. Parametreista vain äänen perustaajuus muuttui tilastollisesti merkitsevästi työpäivän aikana. Vähäiset akustiset muutokset saattoivat johtua siitä, että työpaikan akustinen ympäristö oli hyvä eikä vaatinut työntekijöitä nostamaan äänensä tasoa. Akustisten parametrien selvittäminen jatkuvasta puheesta, joka oli nauhoitettu todellisessa työympäristössä (vrt. laboratorio-olosuhteet) ja aidoissa puheviestintätilanteissa, todettiin kuitenkin mahdolliseksi tavaksi tutkia äänen tuottoa. Kirjoittajan käsityksen mukaan tämä on myös ensimmäinen kerta, kun käänteissuodatusanalyysiä on käytetty todellisessa työympäristössä nauhoitetun jatkuvan luonnollisen puheen tutkimiseen. Tämän lisäksi vertailututkimus kahden eri käänteissuodatusmenetelmän välillä osoitti niillä saatavien tulosten olevan niin yhteneviä, että käänteissuodatusta voidaan pitää lupaavana työvälineenä tulevaisuuden työäänen tutkimuksissa.

Asiasanat puhetyö, puhelintyö, äänenkäytön koulutus, akustinen puheen tutkimus, käänteissuodatus

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Helsinki University of Technology
Finland

Phoniatric Department
ENT Clinic
Helsinki University Central Hospital
Finland

PREFACE

Ken uskovi toteen, ken unelmaan,
viis siitä, kun täysin sa uskot vaan,
sun uskos se suurin on totuutes -
usko, poikani, unehes!
- Eino Leino -

I had never thought of myself as a researcher. Writing my Master's Thesis in winter 1999 was not an easy bite. But, in June 2000, I had just participated in the fancy Promootio-party, a conferment of academic degrees, at the University of Helsinki. The following week my chief at the Helsinki University Central Hospital (HUCH), Phoniatric department, Professor Erkki Vilkman, happened to ask if I would be interested in making a Ph.D. thesis in a project he had launched. "A chance for another fancy party!", I thought, and agreed. But, of course that was not the main reason for my decision. The project in the field of occupational voice care was of my great interest!

I am truly grateful for Professor Vilkman for believing in me and giving me this opportunity. He opened the door for me to the interesting world of occupational voice science. I have been eager to learn more and thankful of the possibility to continue my studies. Thank you for giving me this chance!

Another important person is Professor Paavo Alku, who became my supervisor when I entered the Laboratory of Acoustics and Signal Processing at the Helsinki University of Technology (TKK). No words are enough to thank him. I deeply appreciate his guidance and patience. His support has been essential for this work. I also want to thank Paavo as a friend; you will always remain dear to me.

I started to work at the Acoustics laboratory at TKK in the beginning of year 2001. Our dear gang of Siberia has become close to me: Cumhur, Tuomas, Henkka, Jykke, Mairas, Hannu, and especially Tomppa. I also want to mention Professors Matti Karjalainen, Unto Laine, and Vesa Välimäki, lab secretary Lea Söderman, and Hanna, Juha, Mara, Hynde, Miikka, Ville, Carlo, and Toni. I thank you all for the fun times we have had, parties, other special events, the merry music sessions, interesting lunch discussions, and everything else. The better I have got to know you, the more I have enjoyed your company, and it has been great to become one of you. I think the atmosphere in our lab is unique. These have been happy years for me and I will miss you very much. Especially I want to thank Eva, Laura E. and Heidi-Maria, the ladies I have shared a room with during the years, and who have become my true friends. We have shared the deadlines, stress, personal life struggles and supported each other in many ways. But importantly, we have mostly had fun times together both at work and on our spear time.

During May-August 2003 I had an opportunity to visit the Royal Institute of Technology, Kungliga Tekniska Höskolan (KTH), in Stockholm, Sweden, as a Marie Curie Fellow. It was educative to see another work community from the same research field and in another country. I was also lucky to get to know a bunch of nice people,

from who I want to name especially Professors Johan Sundberg and Sten Ternström, Head of Department Anders Askenfelt, and Anders F., Anick, Giampi, Kjetil, Maria, Roberto, Sofia, and Svante. And Anke, Emilia, and Jordi, the other MC Fellows of that summer. Of the other international contacts I have been able to establish I want to mention Jan Švec, Ph.D., and his wife Hana Svecova.

To write articles is not only individual work. My co-authors have been Professors Paavo Alku, Johan Sundberg, and Erkki Vilkman, and Matti Airas, M.Sc., Eva Björkner, Pd.D., Tom Bäckström, D.Sc.(Tech.), Laura Laaksonen, M.Sc., and Leena Rantala, Ph.D. Ms. Lea Söderman has helped with many practical issues. Besides them, I want to thank Professor Anne-Maria Laukkanen, Docent Marketta Sihvo, Jaana Sellman, Ph.Lic., and Susanna Simberg, Ph.D., for interesting collegial discussions every now and then along the way. In the maintenance of proper language of this thesis I have been guided by Luis Costa, Lic.Sc.(Tech.).

The work has been financially supported by the Academy of Finland, the Finnish Cultural Foundation, the Finnish Work Environment Fund, TKK, and Korvatautien tutkimussäätiö. The pre-examiners of this thesis were Professor Philip Dejonckere, and Docent Eeva Sala. Docent Stellan Hertegård, M.D., accepted to serve as my opponent in the doctoral defense.

Besides this dissertation, I have had also other jobs during these years. I want to thank the people at the Phoniatric department at HUCH for a nice work community. As a voice trainer I have a regular contact with Infor; It's a delight to co-operate with you!

All in all, I feel that my life is rich. I have been blessed with many true friends not yet mentioned: Jojo, Helena, Katriina, Maria, Taina, and Tanja, and with other nice friends and relatives. I also want to cherish the memory of my late mother who died in cancer in August 2001.

Finally, I praise my loved ones: my boyfriend Jan-Erik, my father Kari, his partner Virve, my cousin Satu and her family, my godmother Kaisu, and my colleague and friend Pauliina. Thank you for being there for me!

In Espoo
June 8, 2007

Laura Lehto

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LIST OF PUBLICATIONS

[Study 1] Lehto L, Rantala L, Vilkman E, Alku P, Bäcktröm T, ”Experiences of a short vocal training course for call-centre customer service advisors”, *Folia Phoniatrica et Logopaedica*, 2003; 55: 163-176.

[Study 2] Lehto L, Alku P, Bäcktröm T, Vilkman E, “Voice symptoms of call-centre customer service advisors experienced during a work-day and effects of a short vocal training course”, *Logopedics Phoniatrics Vocology*, 2005; 30(1): 14-27.

[Study 3] Lehto L, Laaksonen L, Vilkman E, Alku P, ”Changes in objective acoustic measurements and subjective voice complaints in call-centre customer-service advisors during one working day”, accepted for publication in *Journal of Voice*.

[Study 4] Lehto L, Laaksonen L, Vilkman E, Alku P, “Occupational voice complaints and objective acoustic measurements – Do they correlate?”, *Logopedics Phoniatrics Vocology*, 2006; 31(4): 147-152.

[Study 5] Bäcktröm T, Lehto L, Vilkman E, Alku P, ”Automatic pre-segmentation of running speech improves the robustness of several acoustic voice measures”, *Logopedics Phoniatrics Vocology*, 2003; 28(3): 101-108.

[Study 6] Lehto L, Airas M, Björkner E, Sundberg J, Alku P, “Comparison of two inverse filtering methods in parameterization of the glottal closing phase characteristics in different phonation types”, *Journal of Voice*, 2007; 21(2): 138-150.

AUTHORS CONTRIBUTIONS

Originally, the initiation to gather data studied in this thesis came from the largest Finnish telecommunications operator Sonera (currently known as TeliaSonera Finland Oyj) in an effort to gain knowledge about the voices of their call-centre personnel. Sonera contacted Professor Erkki Vilkman due to his extensive career in occupational voice research. With support from the Finnish Foundation of Occupational Health, Sonera Corporation started a project called “ASP äänessä - puhelinneuvojien äänen kuormittuvuuden ja äänenkäytön koulutuksen vaikuttavuuden tutkimus” (Telephone customer workers, fatigue in their voice, and the effects of voice training), whose leader was Professor Vilkman. Professor Paavo Alku from the Helsinki University of Technology, Laboratory of Acoustics and Signal Processing, had previously worked in co-operation with Professor Vilkman on many projects and offered working facilities to the author. He has been the primary instructor of the thesis. In addition to Professors Vilkman and Alku, the author has received help and ideas from Matti Airas, M.Sc., Tom Bäckström, D.Sc.(Tech.), and Laura Laaksonen, M.Sc., who have all worked in speech analysis team at the Helsinki University of Technology, Laboratory of Acoustics and Signal Processing. The author has also co-operated with Leena Rantala, Ph.D., Professor Johan Sundberg, and Eva Björkner, Ph.D. All the aforementioned persons have contributed as co-authors, and their tools, expertise, practical endorsement, and collegial support has been essential in writing the publications that make up this thesis.

In [Study 1] the data was analysed by co-author Rantala, Ph.D., who also wrote a Finnish report for Sonera before the author began in the project. The author continued by translating the questionnaires to English, by performing a literature review of the topic, and by writing the journal article. In [Study 2] the author measured all the questionnaire responses, ran the statistical analyses, and was responsible for the writing of the article. In [Study 3] the author performed acoustic analyses both from the speech pressure waveforms and from the glottal flows, and was responsible for writing the article. [Study 4] covered the data which were measured by the author in connection with Studies 2 and 3. The author was responsible for writing the article. The first author of [Study 5] was Tom Bäckström, D.Sc.(Tech.). The author of the thesis was responsible for both planning and running an intra-operator variance test on the material. In addition, she organized inter-operator variance measurements with 13 subjects as operators. The author trained each naîve operator prior to the actual measurement. She also contributed in writing the article. In [Study 6] the author was one of the three experts using the semi-automatic inverse filtering method. She was also the main author of the article. In all the studies the co-authors not yet mentioned have participated in the preparation of the articles by doing statistical analyses, on commenting on the manuscripts, and by offering their scientific expertise on the topic.

1. INTRODUCTION

This thesis deals with the occupational voice. In modern society, there is an increasing demand for oral communication in many professions. The label ‘occupational voice’ refers to those occupations where voice is an essential tool. The people in these occupations often suffer from voice symptoms to varying extents (Scherer et al., 1987; Koufman & Blalock 1988; Sapir et al., 1990; Fritzell 1996; Titze et al., 1997; Mattiske et al., 1998; Morton & Watson 1998; Newman & Kersner, 1998; Smith et al., 1998a; Simberg et al., 2000; Sala et al., 2001: Jonsdottir, 2002; Jonsdottir et al., 2002). There is no clear-cut distinction between the terms ‘occupational voice’ and ‘professional voice’. However, the latter primarily brings to mind the singer and actor, while the former includes all employment categories wherein a clear, dependable, adequately strong and/or pleasant voice is a prerequisite (Casper, 2001). It has been estimated that a well-functioning voice is essential to one third of the current labour force (Laukkanen, 1995; Verdolini & Ramig, 2001; Vilkman, 2004).

The most commonly studied group of professional voice users are teachers. This is understandable, because teachers constitute the largest professional groups depending on voice (Laukkanen, 1995). Many studies have indicated frequent vocal symptoms among teachers (Pekkarinen et al., 1992; Gotaas & Starr, 1993; Sapir et al., 1993; Smith et al., 1997; Mattiske et al., 1998; Russel et al., 1998; Sala et al., 2001; Roy et al., 2004a). Furthermore, in the teaching profession both the endurance of voice and its quality in speech-communication situations are both of great importance.

In this thesis the target group of professional voice users is that of telephone customer service advisors (CSA). The use of voice in various professional and social contexts is constantly growing (Vilkman, 2000) due to the prevalence of new speech technology applications, such as mobile phones. Telephone services are an example of expanding modern-day speech-related professional contexts. Today, many companies reorganize or outsource their customer service functions and this has resulted in an increasing number of call-centre attendances. Telephone personnel constitute a special subgroup of employees because their working ability depends exclusively on their voice. On the telephone, the speaker must rely solely on his/her voice without support from body language or written communication. On the other hand, communicating in telephone customer service is closer to a dialogue than a monologue, which makes it different from, for example, the work of teachers. Therefore, CSAs have a chance for short-term recovery during the calls which might help them to preserve normal voice function (Yiu & Chan, 2003). This recovery, however, is not sufficient as reflected by the large prevalence of voice problems among employees working on telephone services (Jones et al., 2002).

An occupational disease is defined as a disease most likely to be caused by exposure at work. The term occupational voice refers to voice use which is an essential part of the work task. It is assumed that this kind of work, at least to some degree, induces voice loading, which in turn causes voice fatigue and other related symptoms. The voice is affected by many factors that might disturb its production. The risk factors include background noise, poor room acoustics, long speaking distance, poor quality of air (dryness, dust), poor working posture, and voice loading per se by speaking or singing (Vilkman, 1996). Insufficient pre-professional voice training is also thought to contribute to the voice problems of occupational voice users (Ohlsson & Löfqvist, 1987; Vilkman, 2001).

Voice problems have a negative effect on the quality of life of those who suffer from them (Ma & Yiu, 2001; Yiu, 2002; Roy et al., 2004a), but they also burden society with additional health-care expenses (Verdolini & Ramig, 2001). Although the awareness of occupational voice problems has increased, health-care and occupational safety for voice users are less than optimal (Vilkman, 2000). According to the European OS&H legislation, the employer is obliged to provide 'the prevention of occupational risks, the protection of safety and health, the elimination of risks and accident factors, the informing, consultation … and training …, as well as general guidelines for the implementation of the said principles' (Council Directive, 1989). To meet this challenge, occupational voice users should be provided with basic knowledge of voice production and vocal care. The educational approach should help the subject to identify any factors that might contribute to a voice problem, guiding them to avoid and to modify their vocal behaviour before any damage occurs (Duffy, 2003). Proper treatment of voice plays a key role in restoring and preserving the individual's occupational capacity (Ramig & Verdolini, 1998). Vilkman (2004) has presented the term "vocoergonomics" (voco- = voice, ergo- = work, -nomics =

arrangements) in order to emphasize the “voice as a tool” aspect in occupational voice care.

Originally, initiation to gather data studied in this thesis came from the largest Finnish telecommunications operator Sonera (currently known as TeliaSonera Finland Oyj) in an effort to gain knowledge about the voice of their call-centre personnel. At Sonera, it had been noted that the call-centre personnel had more sick-leave than the other groups of employees, and the company therefore wished to analyse the reasons for this. The objective of the company was to improve the working environment of the help-desk personnel and to cut down the incidence of voice failures leading to sick leave.

The first goal of this thesis was to investigate to what extent call-centre customer service advisors experience voice problems. Secondly, the aim was to find out how call-centre customer service advisors benefit from voice training. Both of these topics were studied via questionnaires. The third goal was to investigate how changes in voice during a working day could be measured objectively using information embedded in the acoustic speech signal. In particular, the inverse filtering method was exploited to study voice production of occupational voice users. To the best of the author’s knowledge, this was the first time continuous natural speech collected in a realistic environment was used in such analyses.

2. OCCUPATIONAL VOICE

The use of voice can result in vocal loading. Vocal loading is a combination of prolonged voice use and “*additional loading factors (e.g. background noise, acoustics, air quality) affecting the fundamental frequency, type and loudness of phonation or the vibratory characteristics of the vocal folds as well as the external frame of the larynx*” (Vilkman, 2004, p.220). Figure 1 illustrates the different stages of voice loading (adapted from Vilkman 2005). According to Sillanpää and Saarinen (2004), the loading effect of work can be considered to include work assignment and work performance. In the working assignment, the environmental and personal factors are elements which define the load. Work-related exposure (work arrangements) are reflected by the prevailing conditions resulting in loading. Additionally, work performance leads the employee to experience loading-borne strain. In this context, strain should be interpreted from a wider perspective as uncomfortable experiences in the well-being or in the use of voice. If the person is able to cope with the strain the resulting response is experienced as unproblematic vocal health. However, if the strain is frequent it may lead to a response, for example the emergence of voice symptoms. The amount of voice use causing such symptoms varies greatly between persons. The most common hazards experienced by occupational voice users are vocal fatigue and hoarseness (e.g. Sapir et al., 1990; Sapir, 1993; Scott et al., 1997; Koufman & Blalock, 1988; Sala et al., 2001). It is worth noticing that in the literary of occupational voice research the term vocal loading is typically used when referring to the concept of response in the description above.

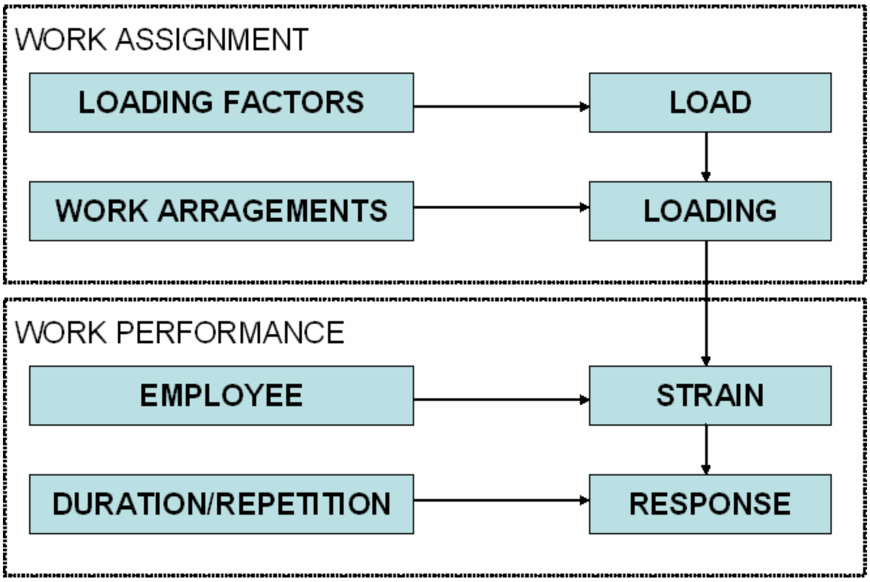

Figure 1: Loading effects of work. (adapted from Vilkman, 2005; Sillanpää & Saarinen, 2004)

Vocal fatigue is a subjective term, which refers to negative sensations related to voice loading. In physiology, fatigue is defined as a state induced by heavy work and associated with a decrease in performance capacity. Fatigue can trigger a protective mechanism that discourages the individual against overstraining him- or herself, and allows time for the recuperative process to occur (Kroemer & Grandjean, 1997). Vocal fatigue is a broad topic that involves a variety of etiologies and symptoms (Scherer et al., 1987). Usually it is described as a negative sensory vocal symptom that corresponds to a change in vocal quality, deterioration of vocal control, discomfort in voice production areas and/or vocal limitations. A fatigued voice may sound hoarse in the ears of the listener or to the speaker him- or herself, voice production is felt to be more laborious, and this may eventually lead to a weak voice or an inability to produce voiced sound at all. The speaker may also have symptoms such as an urge to clear the throat, a feeling of mucus or a lump in the throat, etc. (Scott et al., 1997). In other words, vocal fatigue affects the entire speech communication chain in many ways.

Voice problems can be investigated by many methods such as subjective evaluation (usually with a questionnaire), perceptual evaluation of voice features (performed by the person himself and/or by a clinician), clinical examination, and objective analysis of the speech signal. The task of establishing a self-perceived voice problem, however, may be challenging because it has been found that it does not necessarily correlate with the degree of voice-quality impairment measured acoustically and/or identified perceptually (Ma & Yiu, 2001).

According to Mattiske et al. (1998) and Verdolini and Ramig (2001), studies on professional voice often lack an operational definition of what could be considered a voice problem or a voice disorder. In the literature, voice fatigue, voice symptoms, voice problems, and voice disorders are all terms used when studying occupational voice and its loading. For example, Roy et al. (2004b) defined self-reported **voice problems** broadly as "*any time the voice doesn't work, perform, or sound as it normally should, so that it interferes with communication*." This definition does not differ greatly from the one given for **voice disorder** by Coyle et al. (2001): "*voice disorders may result from changes in the structure and/or function of the laryngeal mechanism that do not allow the mechanism to meet the functional voicing needs of the speaker*".

To clarify the use of terms, it would be advantageous to clearly define the different phases of voice loading. As a response to this inconsistency of terminology, the author of this thesis suggests the following scheme: The first signs of voice loading cause vocal fatigue which emerges as **voice symptoms**. When these symptoms exceed in amount and/or duration a certain limit, which is unique to each person, it is experienced as a **voice problem**. Then, if people suffering from voice problems seek clinical help, they are usually diagnosed as having a **voice disorder**. In addition, the threshold for seeking clinical help varies greatly between individuals. Voice disorders, when finally diagnosed, can vary from mild to severe. Voice disorder always implies voice symptoms experienced as problems, but experiencing symptoms does not always mean that a person has a voice disorder. In this thesis, the terms voice symptoms and voice problems are used most often and they refer to the same phenomenon.

2.1. Voice production and voice loading

In order to understand voice loading, it is useful to discuss the fundamentals of the voice production process. 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 (Buekers, 1998a). The vocal mechanism involves the coordinated action of many muscles, organs, and other structures in the abdomen, chest, throat, and head. Indeed, virtually the entire body influences the sound of the voice either directly or indirectly.

The vocal folds are the origin of the human voice. When air flows from the lungs, the vocal folds start to oscillate. During respiration, the vocal folds are widely separated (abducted), but during phonation they are brought close to each other (adducted). Periodic opening and closing of the orifice between the vocal folds, the glottis, results in “puffs” of air that excite the vocal tract. In other words, the voice source of speech is a (quasi)periodic train of airflow pulses (see for more details section 4.3.). By regulating the vibration of the vocal fold, a speaker can change, for example, the vocal intensity and phonation type. When vocal folds are adducted with great force, the voice typically becomes pressed. This often happens when the volume of voice is raised with only muscular effort (compared to support from the breathing system).

The vocal folds are composed of several layers. Mucosa forms a thin, lubricated surface of the vocal folds that makes contact when they are closed. The vibration itself requires only little muscular work in the larynx. The vibration is maintained by air pressure variations and the elasticity of the tissues. Every time the vocal folds vibrate, they collide to each other. These collisions may lead to injuries of the tissue if the glottal adduction is strong over a long time span. Minor tissue changes like vocal fold thickening and vocal nodules are often considered functional or behavioral (Fawcus, 1986; Boone, 1987). Vilkman (2004) has equated the repeated vocal fold movements and collisions with repetition strain injuries, such as “tennis elbow”. According to textbooks of occupational medicine, repetition strain injuries are caused by an overload of repetitive movements and static and dynamic muscle loading combined with biomechanical, ergonomic, and physiological factors as well as poor treatment of early symptoms (Dalton & Hazelman, 1987). Therefore, it can be argued that repeated vocal fold movements lead to voice loading in many cases.

The differentiation between a pathologic voice and a normal one is complicated. The quality of voice varies on a continuum between normal and abnormal extremes. Speakers who have no pathology in the larynx may produce hoarse voice and people with certain laryngeal pathologies, on the other hand, do not necessarily reveal appreciable vocal disturbances until a considerably advanced stage (Treole & Truedeau, 1997). In case of occupational voice problems, however, persons own concern about his/her voice symptoms and related reductions in physical, social, emotional and/or professional well-being should be taken into account in order to sustain their occupational capacity (Ramig & Verdolini, 2001).

2.2. Voice loading factors

According to the present understanding, there are many reasons underlying voice problems. Figure 2 presents the environmental, working task dependent, personal and other factors related to voice loading (adapted from Vilkman, 2004). These are in particular ergonomics, air quality, background noise, room acoustics, amount of voice use, voice production habits, status of overall health and psychosocial factors. This subsection will briefly discuss the abovementioned factors.

2.2.1. Ergonomic factors

The working posture is an essential issue in ergonomics and has also been shown to be connected with voice function. Posture affects especially breathing patterns, which are critical to normal voice production (Hoit, 1995). In voice therapy it is assumed that a straight position of the neck facilitates an economic control of the breathing process, whereas a glancing position of the head will lead to breathing problems. Consequently, tension is increased in the throat and neck muscles, which can cause hoarseness and a variety of symptoms, especially pain and fatigue associated with talking. Thus, muscle tension and diverging posture seems to lead towards tensed voice production (Kooijman et al., 2005; Thomas et al., 2006)

Repetitive strain injury involves rapid fatigue and pain of the affected body part, or even inability to use the body part due to repetitive use. It may affect also the vocal mechanism (Verdolini et al., 1998; Vilkman, 2004). In computer work, for example, it is manifested in hands and arms, and affecting the posture. Considering the use of voice in a sitting position, which is common for telephone employees who are the focus of this thesis, two harmful working postures are common. One is the position where the upper part of the back bends down while the shoulders are pushed forwards. In the other, the head leans forward, which causes tension in the neck and throat. These positions require excessive tension in the neck and laryngeal muscles, which changes the speaking technique and may result in a voice problem. The sitting position has been found to be connected to a more effortful voice production than the standing position (Vilkman et al., 1997; Vintturi, 2001).

2.2.2. Air quality

The different factors affecting air quality are humidity, cleanness, and temperature. Of these, the effect of air humidity on professional voice users has been studied the most. To vibrate easily and resist injury, the vocal folds need to be kept moist, both internally and externally. Dry air, breathing through the mouth, smoking and certain drying medication all dry the vocal folds externally, while drinking too much caffeine or alcohol and not drinking enough water dries them internally (Verdolini et al., 1998). A series of studies have indicated that drying affects negatively certain aspects of vocal performance (Verdolini-Marston et al., 1990; Verdolini et al., 1994; Vilkman et al., 1997; Richter et al., 2000; Vintturi et al., 2001a). A decrease in relative humidity had a significant effect on the acoustic parameters after only 10 minutes of provocation (Hemler et al., 1997). Dry air has been associated with strenuous voice production and vocal symptoms during voice loading tests in laboratory conditions

(Vintturi, 2001). In a study by Jones et al. 2002 on telemarketers, those employees who experienced their working environment air to be dry were significantly more likely to have indicated that their work was affected. In speaking environments, high temperature is usually associated with dry air.

Smoking is among the most common air cleanliness factors affecting occupational voice users. Primary and secondhand smoke passes through the vocal folds causing significant irritation and swelling in them. This will change voice quality, nature, and capabilities (Verdolini et al., 1998). Other causes for contaminant air are different chemicals or smoke. Even a low concentration of formaldehyde, which for example new furniture often contains, is known to affect the mucous membrane of the respiratory tract (e.g. Lemiere et al., 1995). Welding fumes are found to cause voice problems (Ohlsson et al., 1987).

2.2.3. Room acoustics and background noise

Background noise forces the speaker to raise their voice to be heard. Speakers who raise their loudness of phonation also tend to raise their fundamental frequency (Baken, 1987; Gramming, 1991; Lauri et al., 1997) and therefore increase also the frequency of vocal fold vibrations. It is generally assumed that persons who have to speak loudly are at great risk for developing voice problems. A need to raise ones voice might be due to background noise, poor room acoustics, and long speaking distance. Different types of background noise at working places are speech babble (such as pupils in a classroom or office workers in an open-plan office), disturbing ventilation or air conditioning noise, or external reasons such as traffic noise.

High background noise levels have been found in day care centres (Sala et al., 2002; Södersten et al., 2002). It was estimated that it even disturbed speech communication Sala et al., 2002). In schools, poor classroom acoustics may also cause other related problems, such as disciplinary issues, as noisy environment might have an impact on the pupils' concentration and thus raise noise levels (Knecht et al., 2002). Inefficient student discipline has been found to be one of the factors contributing to voice problems in teachers (Yiu, 2002).

Although the effects of background noise are studied extensively in teaching professions, they have been surveyed in other occupations, too. Welders have found to have significantly more voice problems than clerks although the welders talked only one tenth of their working time compared to the clerks (Ohlsson et al., 1987). This was due to the difference of noise level which was 95dB for welders compared to ca. 40dB in the office environment (Ohlsson et al., 1987). However, welders are also affected by poor air quality, as mentioned in section 2.2.2.

2.2.4. Amount of voice use

Although voice quality requirements and vocal load may vary in different professions, professional voice users all depend on vocal endurance. Among teachers, the amount of voice use, that is the relative time the speaker actively uses his/her voice production apparatus, was found to be around 20% of the working day (Masuda et al., 1993; Södersten et al., 2002). Day care centre teachers have been found to speak a minimum of 19% and a maximum of 63% of the working time (Sala et al., 2002).

In few studies, the amount of vocal fold vibration has been investigated by calculating the so called index of voice loading (Rantala & Vilkman, 1999; Rantala et al., 2002). Voice complaints correlated strongly with high values of the index (Rantala et al., 2002). The index of voice loading estimates the number of oscillations during a working day by multiplying the time spoken (in seconds) and F0. Vilkman (2004) suggested that occupational voice disorders are related to an excessive amount of vocal fold oscillations. During each vibration the vocal fold mucosae collide with each other. Also, Titze (1994) pointed out that phonation is the only activity where humans allow vibration and colliding body tissues at a high rate (hundreds of vibrations each second). These collisions can lead to tissue changes, most common of which are nodules of the vocal folds. For example, teachers, who are known to be the occupational group seeking most help for voice disorders (Fritzell, 1996; Titze et al., 1997; Morton & Watson 1998), suffer from a high incidence of vocal nodules compared to persons in other occupations (Coyle et al., 2001). Day care centre teachers have found to have moderate or more severe voice symptoms four times more compared to nurses (Sala et al., 2001). Females generally report voice problems more often than males (Morton & Watson, 1998; Russel et al., 1998).

2.2.5. Health-related factors

There are a number of factors which may affect the vocal fold mucosa or the respiratory ability to support speech. These are, for example, smoking (Sapir, 1993; Garret & Ossoff, 1999), hydration (Garret & Ossoff, 1999), medication (Garret & Ossoff, 1999), respiratory illnesses, chronic allergic rhinitis, sinusitis (Vilkman, 2000; Garret & Ossoff, 1999; Long et al., 1998), gastroesophageal reflux (Garret & Ossoff, 1999), and general physical condition (Vilkman, 2000). In addition to the direct effect these conditions have on the voice, it is likely that the speaker develops further compensatory behavior that may worsen the voice problem (Williams & Carding, 2005).

Temporary voice problems are due to infections of the upper airway caused by common cold. Laryngitis can be acute, because of viral or bacterial infection, or it can be a chronic disorder. Reflux laryngitis is one form of chronic laryngitis that has an impact on voice. A leakage of stomach acid back up the esophagus onto the vocal folds and causes redness and irritation on the tissues of the vocal folds. According to Verdolini et al. (1998), there are many studies which show that this irritation may cause voice problems in a large percentage of patients. However, a Cochrain review on acid reflux treatment for hoarseness was unable to make firm conclusions regarding the effectiveness of anti-reflux treatment for hoarseness (Hopkins et al., 2006).

Respiratory allergies contribute to voice problems (Gotaas & Starr, 1993), and asthma is a wide-spread disease that affects persons of all ages (Ihre et al., 2004). It causes inflammation of the bronchi, which gives rise to mucus causing coughing and throat clearing. Asthma is most often treated with inhaled corticosteroids. Inhalation of cortisone is known to cause voice disturbances (Ihre et al., 2004).

2.2.6. Psychosocial and psychoemotional factors

Stress implies a degree of activation that is inefficient or too high to manage and is detrimental to the performance (Wellens & van Opstal, 2001). Emotional stress, the personal life situation, and at least parts of the personal life history are issues that can affect the voice (Roy et al., 2000). Psycho-emotional stress can cause, in combination with intensive voice use, tensions in head and neck muscles (Seifert & Kollbrunner, 2006; Kooijman et al., 2005). Stress may reduce behavioral efficiency and disturb voicing. Also, the occurrence of vocal symptoms and voice disorders in professions where voice is an essential tool may cause stress and anxiety (Wellens & van Opstal, 2001).

Several authors have mentioned psychological stress as a factor contributing to voice problems among teachers (Gotaas & Starr, 1993; Sapir et al., 1993; Morton & Watson, 1998). Factors influencing the experience of voice complaints are stress, work pressure, composition of the group communicated, disrespectful behaviour of pupils and noise in classrooms caused by misbehaving pupils (Simberg, 2004; Thomas et al., 2006). In a study by Jones et al. (2002) those telemarketers who frequently experienced stressful calls were significantly more likely to have indicated that their work, including voice use, was affected.

2.2.7. Voice production habits

As to the individual variation in voice endurance, it is well known that some individuals tolerate enormous amounts of loading, while others, even despite a good vocal technique, are prone to develop vocal symptoms already after moderate loading (Vilkman, 1996). This is likely to be based on genetic variations in the biomechanical properties of the vocal folds (Gray & Thibeault, 2002). However, if a speaker constantly uses his/her voice extensively with a poor voicing habit, voice symptoms are likely to occur (Williams & Carding, 2005). Inappropriate breathing and insufficient rest have also been named as contributing factors of voice problems (Yiu, 2002).

Speech-related personality factors include the tendency of a person to habitually speak loudly, excessively, and rapidly (Sapir et al., 1992). Percussive speaking, that is too loud use of voice or stressing the first syllable of each word, is also an improper speaking technique that may result in muscles getting fatigue. The personality factors “I talk more than others” and “I talk louder than others” were significantly associating with reporting disturbing voice problems also in a study of telemarketers (Jones et al., 2002).

The educational programs for voice users who are required to have a high quality of voice in their occupation, such as singers and actors, include voice training. However, persons exposed to high voice loading (teachers, salespersons, military, clergy) are only provided training occasionally and usually at the worker's own initiative. Insufficient pre-professional voice training is thought to contribute to the voice problems of occupational voice users (Ohlsson & Löfqvist, 1987; Sapir, 1993; Mattiske et al., 1998; Vilkman, 2001). Some may also regard their vocal symptoms as inherent to their occupation and do not therefore seek for professional help (Morton & Watson, 1998). Hence, preventive voice care needs to be emphasized as a tool to sustain occupational capacity.

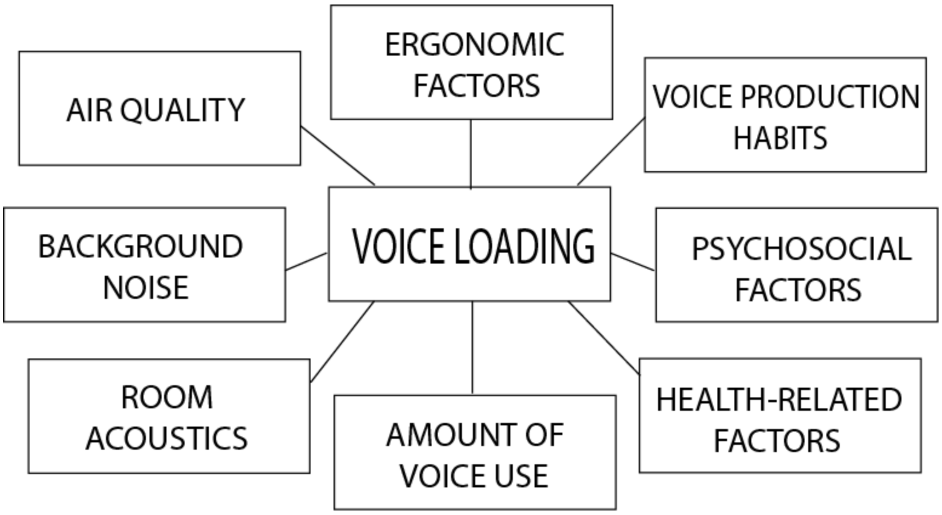

Figure 2: Factors related to voice loading (adapted from Vilkman, 2004).

2.3. Prevalence of voice problems in working population

Prevalence of voice problems have usually been investigated within a specific occupational group or among those seeking help from voice clinics. Therefore, studies estimating the occurrence of problems throughout all voice users are sparse. According to the review by Raming and Verdolini (1998), various studies concerning the population of the US have reported the frequency of occurrence of some kind of voice abnormality at any given moment in time to be from 3% to 9%. In a study performed in Scotland, the prevalence of voice problems among the general population was found to be around 7% (Hannaford et al., 2005). However, a telephone survey by Roy et al. (2005) found that a lifetime prevalence of a voice disorder among the general population was found to be as high as ca. 30%.

Voice problems occur with a change in the voice, often described as hoarseness, roughness, or a raspy quality. People with voice problems often notice or complain about changes in pitch, voice loss, loss of endurance, and sometimes a sharp or dull pain associated with voice use. Other voice problems may accompany a change in singing ability that is most notable in the upper singing range. The definition of a voice disorder in an occupational context depends on the demands set upon the voice. Especially the need for voice endurance is an essential criterion (Vilkman, 2004).

A questionnaire study is the most common way to investigate the prevalence of occupational voice problems. Also in this respect teachers are the occupational group that has been studied most extensively. Teachers have been found to be the largest group among those seeking medical help for voice problems (Herrington-Hall et al., 1988; Fritzell, 1996). According to several research questionnaire studies, 20 to 80 percent of teachers have reported that they suffer from various voice symptoms (Gotaas & Starr, 1993; Sapir et al., 1993; Smith et al., 1997; Morton & Watson, 1998; Russel et al., 1998; Sala et al., 2001; Roy et al., 2004b). These studies have investigated voice symptoms that are not yet diagnosed as voice disorders. Other widely studied occupational groups are day care centre teachers (e.g. Sala et al., 2001), singers (e.g. Phyland et al., 1999) and actors (e.g. Novak et al., 1991). In addition, army (e.g. Sapir et al., 1990), and aerobic instructors (e.g. Long et al., 1998) have been studied.

Previously only Jones et al. (2002) have studied telephone employees, who represent an occupational group similar to that focused on in this thesis. In order to collect data, they contacted three reservation centres, an outbound telemarketing firm, a messaging company, and a telephone survey research firm. A total of 304 employees completed the survey. It was found that 68% of the telemarketers reported one or more symptoms of vocal attrition. Half of them had missed work because of their voice problems. Compared to college students, who served as a control group, telemarketers were twice as likely to report voice problems.

3. OCCUPATIONAL VOICE CARE

It has been stated that the goal of voice care, in general, is to restore the best voice possible; a voice that will be functional for purposes of employment and general communication (Colton et al., 2006, p.321). The educational approach can help individuals to identify factors that may contribute to a voice problem, to alter and avoid these factors, and to modify vocal behavior before any damage occurs (Duffy, 2003).

There is plenty of evidence that only a small percentage of teachers who report voice problems seek professional help (Sapir et al., 1993; Russel et al., 1998; Smith et al., 1998b; Roy et al., 2004b). Many teachers regard their vocal symptoms as inherent to their occupation and do not necessarily take appropriate countermeasures (Morton & Watson, 1998; Yiu, 2002). They might also experience that their voice problem is not "severe enough" (Yiu, 2002). Other reasons for not seeing a specialist are the inconvenience of taking time off from work, fear of negative perception by colleagues, or insecurity in the capability of following the advice from a specialist (Smith et al., 1998a; de Jong et al., 2003).

Early identification and treatment of voice problems is thought to reduce their severity and the time needed to recover from them. Also the European occupational safety and health legislation obliges the employer to provide education for prevention of occupational risks by consultation, training and general guidelines (Council Directive, 1989). However, this obligation is not always fulfilled. According to Jones et al. (2002), some firms even declined to participate in the survey on prevalence and risk factors for voice problems among telemarketers because they wished to avoid raising employee awareness of such matters.

3.1. Voice training versus voice therapy

Voice care is carried out either by voice training or voice therapy. Voice training usually means preventative voice care. Conventional voice therapy and preventive treatment differ, primarily, in their goals (Amir et al., 2005). While the former is aimed at recovering from a vocal dysfunction, the latter is aimed at preventing it. The two therapeutic approaches also target different clients. Voice therapy clients typically have initial complaints about vocal symptoms. Additionally, they have usually been examined by a phoniatrician and been diagnosed as having dysphonia before therapy. Conversely, preventive treatment clients, generally, do not complain about vocal or laryngeal symptoms. Instead, the aim is to preserve their vocal health and to teach them how to prevent such problems from occuring. These clients' occupations usually require excessive vocal use (e.g. vocal performers, teachers, sales persons). In addition, people who attend preventive voice treatments are typically not examined by a phoniatrician prior to therapy, since it is often administered in the work place or in some other non-medical setting. Finally, while conventional voice therapy is mostly conducted on an individual basis, preventive voice treatments are commonly conducted in groups (Amir et al., 2005).

3.2. Preventative care of occupational voice

Within the field of occupational voice care, several authors have addressed the importance of the prevention of voice disorders among those whose work requires extensive use of voice (e.g. Sapir et al., 1993; Buekeres et al., 1995; Fritzell, 1996; Smith et al., 1997; De Bodt et al., 1998; Russel et al., 1998; Morton & Watson, 2001; Verdolini & Ramig, 2001; Yiu, 2002; Roy et al., 2004a). This section reviews previous studies on preventative voice care.

3.2.1. Preventative voice training programs

Table 1 summarizes studies on preventative voice training. Those investigations, which focus on preventing voice problems from occurring among professional voice users or persons studying for vocally demanding occupations, have been included. In preventative voice training, there are different types of treatments. These are vocal hygiene instructions, voice care, and guidelines for self-observation. Vocal hygiene education usually strives for increasing the awareness of the following aspects: warning signs/symptoms of vocal fatigue, reduction of volative use of voice, use of some specific strategies to overtake attention without abusing the voice, knowledge of personal vocal limits and of contributing factors (such as vocal cord dehydration, gastroesophageal reflux, incorrect food habits, allergies) (Bovo et al., 2006). Voice care includes both theoretical information and practical rehearsals in posture, respiration, release of tension in the vocal apparatus, resonance and voice projection (Duffy & Hazlett, 2004). Self-observation would include keeping a diary of daily voice use in order to understand the nature of person's own vocal habits (Chan 1994, Bovo et al., 2006). Also the environmental factors are usually discussed, such as ergonomic circumstances and the acoustical conditions of the working place.

In summary, results of preventative voice training indicate that education improves subjects' vocal performance and knowledge of voice care. This can be argued based on various voice therapy studies in which groups receiving therapy have shown better performance than the corresponding control group with no therapy (e.g. Ohlsson, 1988; Södersten & Lindestad, 1990; Carding et al., 1998; McKenzie et al., 2001; Roy et al., 2001; Sala et al., 2001). Voice care knowledge aims at understanding issues of vocal hygiene, limiting vocal hyperfunction, and reducing vocally abusive behavior. "Voice care strategies", "breathing exercises", and "proper voice production methods" are topics that should be included in voice training programs according to practising and prospective teachers (Yiu, 2002). In a study of telemarketers by Jones et al., (2002), 78% of attendances suffering from voice problems desired instructions on caring for their voices. Those with dysphonia have been demonstrated to have a lower level of voice knowledge than people with healthy voices (Fletcher et al., 2007).
Voice training programs have been suggested for all those who are becoming teachers (Simberg, 2004). Teachers at the beginning of their career have been found to complain more than their older colleagues (Kooijman et al., 2006). This emphasizes the importance of adequate targeted prevention programs for future teachers and for starting teachers with regard to their voice (Kooijman et al., 2006). The incidence of voice symptoms has been found to be lowest with teachers having longer-term training (Ilomäki et al., 2005). The incidence of vocal symptoms was higher among teachers with short-term training, even compared to those with no training at all. This indicates that short-term training might lead to increased awareness of vocal symptoms. Thus, the actual prevention of voice problems demands more profound voice education and longer direct training (Ilomäki et al., 2005).

It is important to remember that voice is an instrument affected by many factors (Vilkman, 2004), and voice knowledge education as well as voice training should be a crucial part of its care. However, even consistent treatment does not always work. For example, aerobic instructors were found to demonstrate a high incidence of vocal problems despite being familiar with vocal hygiene information. This could be explained by the intense use of voice the instructors are forced to due to hard music background (Heidel & Torgerson, 1993).

Study	**Subjects**	**Control group**	**Type of treatment**	**Duration of treatment**	**Findings**
Chan (1994)	Kindergarten teachers (n=12)	Kindergarten teachers (n=13)	Vocal hygiene	1.5 hour workshop session followed by daily practice of vocal hygiene for 2 months (diary)	Acoustic analysis: significant improvement in experimental group
Stemple et al. (1994)	Graduate students: - Experimental group (n=12) - Placebo group (n=12)	Graduate students (n=12)	- Exp. group: vocal function exercises - Placebo group: placebo exercise program	Survey lasted 28 days, during which exp. and placebo group did exercises two times a day, 15-20 each time, 7 days a week	Acoustic analysis: experimental group progressed
Broaddus-Lawrence et al. (2000)	Singers trainees (n=11)	-	Vocal hygiene	Four one-hour class	Minimal changes in vocal hygiene behaviors and perceptual voice characteristics, but high degree of benefit and learning
Roy et al. (2000)	Actors (n=27)	-	Hygienic laryngeal release technique (HLR)	Two two-hour HRL training sessions	Acoustic analysis: significant training effect
Duffy & Hazlett (2004)	Teacher trainees - Indirect group (n=20) - Direct group (n=12)	Teacher trainees: (n=23)	- Indirect group: vocal hygiene - Direct group: voice training	Not clearly explained	- Direct group: acoustical changes, no self-reported symptoms - Indirect group: raised awareness - Control group: deterioration of voice
Timmermans et al. (2004)	Actors and radio directors (n=23)	Film and TV directors (n=23)	Vocal hygiene and vocal training	Survey lasted for 18 months, including 30 h vocal hygiene and 30 h vocal training a year	Overall grade of voice improved
Bovo et al. (2006)	Kindergarten and primary school teachers (n=21)	Kindergarten and primary school teachers (n=20)	Vocal hygiene, vocal training and directions for self-observation	12 h within three months	Improvement measured acoustically and with a questionnaire

Table 1. Studies concerning preventative voice training.

3.2.2. Other preventative methods

There are also other ways to prevent occupational voice disorders than voice training. For example, the use of technical aids provided by speech amplifiers has been reported to reduce voice loading of teachers (Sapienza et al., 1999; Jonsdottir et al., 2001). In perceptual evaluation, the overall quality of teachers' voices has been found better and less strained when using amplification. Teachers have also reported easiness of speaking when amplification has been used (McCormick & Roy, 2002; Jonsdottir et al., 2003). Also, students listening to amplified voice have reacted positively (Jonsdottir, 2002). Amplification has also been found to be more effective than vocal hygiene education in a group of teachers already suffering from voice problems (Roy et al., 2002). However, amplification should not be regarded as a substitute to education in vocal hygiene or vocal training, and improvements of the acoustical conditions in classrooms should be taken into more careful consideration (Yiu, 2002; Jonsdottir, 2003).

Voice screening tests have also been suggested as a component in the prevention of voice problems. It has been suggested that voice performance tests should be offered to students who study for vocally demanding occupations (Buekers, 1998a; Simberg, 2004). Their aim is to recommend persons with a potential risk to develop voice problems to choose another profession. However, at present, there is no standard method to evaluate the effect of vocal endurance upon voice performance (Buekers 1998b).

A combination of laryngeal examination, measurement of maximum phonation time, and a perceptual examination of voice quality was found to be a potential method to predict voice problems among teachers (De Bodt et al., 1998). Strictly acoustic evaluations of voice features have also been suggested to be used in screening vulnerable voices. However, results studying the connection between subjective voice complaints and acoustic observation have not reached unanimous conclusions. In studies by Ma and Yiu (2001) and Laukkanen et al. (2004), the self-perceived voice problem did not correlate with the degree of voice-quality impairment measured acoustically. Neither were such connections reported in Study 4 of this thesis. However, the study by Rantala and Vilkman (1999) showed a tendency toward a relationship between subjective voice complaints and objective acoustic measures of voice. Hence, there is still need for future research in this area.

4. OBJECTIVE MEASURES OF SPEECH PRODUCTION IN OCCUPATIONAL VOICE RESEARCH

The dynamic interaction between airflow and vocal fold mass produces acoustic energy. Air erupts from the lungs and makes the vocal folds vibrate. The speech signal is an airborne acoustic wave. Our ears respond to sound as pressure variations in the atmosphere, and these air pressure variations are converted into neural impulses that are sent to the brain for interpretation. When voice is recorded, a microphone converts the air pressure variations into electrical signals (Kent & Read, 1999). Studying the vibration of the vocal folds directly is complicated due to the hidden position of the origin of the voice source. However, accurate and reliable methods to measure vocal fold vibration and the voice source are necessary for gaining information on voice production and in helping to understand the factors affecting it (Hertegård, 1994).

This chapter reviews the objective approaches used in measurements of occupational voice. First of these are measurements performed from the acoustic speech pressure waveform. As an alternative, it is possible to depict the function of voice production by estimating the voice source, the glottal volume velocity waveform. Finally, tools and environments typically used in occupational voice research are shortly described.

4.1. Considerations on experimental arrangements

In the area of occupational voice, speech researchers have traditionally used foremost sustained vowels in voice analysis. A sustained vowel is easy to analyse because it is long and stationary enough for most purposes. However, there has been debate on whether analysis of a sustained vowel is a sufficient representation of human voice communication. Some researchers claim that sustained vowels lack many of the properties that running speech has (Klingholz, 1990; Qi et al., 1999). The most obvious difference between sustained vowels and continuous speech is that the latter is a combination of different utterances and phonemes, and they alternate in rapid succession. Therefore, the analysis of continuous speech sets higher requirements on the speech analysis environment than the analysis of sustained vowels. In order to study occupational voice, the use of continuous speech in natural speaking situations would most accurately reflect real human voice production.

The term continuous speech includes both reading assignments and spontaneous speech. Different kinds of approaches have been used when collecting recorded data for occupational voice research. The studies conducted differ from each other in terms of the loading task and the recording environment. In some investigations, natural speech, produced at work, has been used as the loading task, and the speech samples have been recorded while working (Rantala et al., 1998a; Rantala et al., 1998b; Jonsdottir et al., 2002; Rantala et al., 2002; Södersten et al., 2002). Some studies have also used speech produced at work as the loading task, but speech data have been recorded directly before and after voice loading from reading assignments (Löfqvist & Mandersson, 1987; Novak et al., 1991; Gotaas & Starr, 1993) or from sustained voice production (Kostyk & Rochet, 1998). Other studies have been conducted by using a specific speaking task with data collected in laboratory environments (Gelfer et al., 1991; Stemple et al., 1995; Gelfer et al., 1996; Lauri et al., 1997; Vilkman et al., 1997; de Bodt et al., 1998; Buekers, 1998b; Vintturi et al., 2001a).

There has been a debate on if data collected in controlled laboratory conditions can represent real-life speaking situations at work. It is obvious that laboratory test conditions often differ markedly from real-life working situations where environmental factors such as humidity and dust, besides individual factors like stress and communicative interaction, play a considerable role in voice performance (Buekers, 1998b). For example, a voice interval test, designed to produce voice load, was found to cause more voice fatigue than the working day (Buekers, 1998b). In addition, the strain imposed on the voice mechanism in laboratory environments (e.g. reading a given text) might not be entirely similar to, and thus not comparable with, the potential strain resulting from speaking at work. This might be the case even if the volume of voice production or the background noise of the environment in the two conditions were the same (Rantala et al., 1994).

Collection of speech material in real working environments engenders many challenges as well. Firstly, in field studies it is important that the measurement device is easy to wear and practical to use because the subject usually needs to move around during the recordings. Secondly, the level of background noise must be taken into consideration. In most of the field studies, no such special background noise separation has been done, and the problem has been reduced only by placing the microphone close to the speaker's lips**.** Channel estimation techniques have been used to suppress the site noise (background noise) from the recordings, and to recover only the speech signal (Södersten et al., 2001; Ternström et al., 2002). The technique is also known as speech enhancement, which means that speech signal intelligibility and quality is improved by means of signal processing (Benesty et al., 2005).

4.2. Speech pressure waveform parameterization

The commonly used parameters to measure voice features from recorded speech data are the fundamental frequency (F0), sound pressure level (SPL), harmonics-to-noise ratio (HNR), alpha ratio (AR), and features of perturbation: amplitude perturbation (jitter) and frequency perturbation (shimmer). Perturbation values describe the stability of voice, jitter reflecting frequency, and shimmer amplitude changes in sequental periods. Perturbation measures reflect the speaker's ability to maintain ventilatory and laryngeal capacities to produce a stable voice output (Orlikoff, 1995) and have been used to study the effects of voice loading (Scherer et al., 1987; Gelfer et al., 1991; Rantala et al., 1997; Rantala &Vilkman, 1999; Roy et al., 2000). Harmonics-to-noise ratio, also known as noise-to-harmonics ratio and signal-to-noise ratio, measures hoarseness in the voice. Hoarseness can be caused, for example, by loose adduction of vocal folds (hypofunction). Harmonics-to-noise ratio has also been used in occupational voice studies (Gelfer et al., 1991; Roy et al., 2000).

Studies 3 and 5 involved research on fundamental frequency, sound pressure level, alpha ratio, and the number of vocal fold vibrations. In the following, findings regarding these parameters within the field of occupational voice research are summarized. Analysis programs used in parameterization of speech pressure waveforms are presented in subsection 4.4.

4.2.1. Fundamental frequency

The frequency of glottal vibration determines the fundamental frequency of speech, which is commonly denoted by F0. The perceptual counterpart of F0 is pitch. The fundamental frequency is the most saliently used parameter in voice analysis research. In many studies concerning vocal loading F0 is found to increase**.** From field studies, Rantala et al. (2002) recorded the first and the last lesson of 33 female primary school teachers. F0 increased statistically significantly between the measuring moments. Södersten et al. (2002) compared F0 from spontaneous speech during work to a baseline recorded before working day. Their subjects, ten female preschool teachers, talked with significantly higher F0 during their working hours compared to the baseline. In a field study by Schneider et al. (2006), F0 rose statistically significantly during one hour of teaching in a group of 33 teachers. Also studies conducted in laboratory settings have found F0 to rise statistically significantly, loading tasks varying from 45 minutes to 5 times 45 minutes (Stemple et al., 1995; Vilkman et al., 1999; Laukkanen et al., 2004). One possible explanation for the average F0 rise has been the loudness of environmental noise (Ternström et al., 2002).

Not all studies, however, have found an increase in F0 as a result of voice loading. A study by Neils & Yairi (1987), investigating loading effects of different levels of background noise, did not find any specific changes in the fundamental frequency of six healthy female subjects. De Bodt et al. (1998) investigated 20 female vocal professionals who underwent an endurance test. Although they reported subjective complaints of vocal fatigue, F0 did not change significantly. A field study by Jonsdottir et al. (2002) found an increase of F0 in five teachers when their recording from the first and the last lesson were analysed, but the difference between the measurements was not significant.

A common assumption is that the rise of F0 during voice loading is related to increase of voice problems during a working day. However, a study by Rantala et al. (2002) found that voices of the teachers with few voice complaints changed more systematically than voices of the subjects with many complaints. However, they also found that the overall F0 level of teachers with many voice problems was higher than that of teachers with few voice complaints. Therefore, it was suggested that an increase of F0 due to voice loading might be a normal physiological phenomenon that is more apparent in speakers whose voices are in good condition (Rantala et al., 2002). Thus, a change in physiological functions may illustrate healthy and normal adaptation to a situation, while a lack of change may imply that the vocal organ is not functioning optimally. Fundamental frequency changes have been investigated also without special voice load. F0 has found to rise during a day, but not statistically significantly (Artkoski et al., 2002).

4.2.2. Sound pressure level

In speech science, the term vocal intensity is commonly used to refer to the acoustic energy of speech, and is typically quantified by using the sound pressure level (SPL) (Titze, 1994). It is a parameter measured from the speech pressure waveform, and should not be confused with subglottal pressure, which is the driving force beneath the vocal folds necessary to initiate and maintain phonation.

The perceptual counterpart of SPL is loudness. Speakers who raise their loudness of phonation also tend to raise their fundamental frequency (Baken, 1987; Gramming, 1991). Rising intensity has been shown as an increase in SPL values (Vilkman et al., 2002; Alku et al., 2006). A need to raise one's voice might be due to background noise, poor room acoustics, and long speaking distance, or in order to convey emotional content such as anger in the speech message. The louder a person has to talk, the greater is the strain on the tissues in the larynx (Buekers, 1998a).

Telephone operators, speech therapists and receptionists have been found low speaking intensities (Buekers et al., 1995). Although these professions include extensive amounts of speaking, the phonation consists predominantly of individual communications at low intensities. It is also noticeable, that in these professions the work-place background noise is quite low. For example, in Study 2 of this thesis, the background noise level in an open-plan office for telephone customer service advisors was 42 dB(A). When this is compared to 72-90 dB noise levels in daycare centres (Södersten et al., 2002), it can be understood that voice use in these two surroundings is quite different. It is generally assumed that persons who have to speak loudly are at great risk for developing throat problems. There has also been debate on if the amount of loud talking is more related to vocal fatigue than the amount of talking as such (Sander & Ripich, 1983; Novak et al., 1991; Sapienza et al., 1999). Sometimes, however, subjects who speak with a loud voice also have a tendency to speak for a long time (Masuda et al., 1993). If the intensity of voice needs to be raised, the key factor is an increase of subglottal pressure, but this typically also involves using larger glottal adduction. This, again, can result as hyperfunctional voice production, which in turn might end up as voice fatigue.

Not all studies, however, support the assumption that many voice complaints are connected to increased loudness levels. Teachers with few voice complaints have been found to have a slight tendency to use a louder voice than teachers with many voice complaints (Rantala & Vilkman, 1999). Neither the time that teachers talk nor the amount of time they talk loudly appear therefore not to be solely responsible for vocal fatigue (Gotaas & Starr, 1993). Workday activities, as well as the non-related activities which are vocally and psychologically demanding, may contribute to the development of vocal fatigue.

4.2.3. Alpha ratio

A widely used technique to parameterize the speech spectrum is to measure its spectral skewness, also known as spectral tilt. The alpha ratio is typically defined as the ratio between the spectral energies below and above 1000 Hz. However, the upper and lower limits of bandwidths differ in different formulae. The parameter can also be presented in either the decibel or the linear scale. Furthermore, the lack of consistent definitions (ratio between the energy above and below, or the ratio between energy below and above) might therefore result in either positive or negative parameter values (in dB) presented in the literature.

With studying the spectral changes of speech due to voice loading, the voice production style can estimated. Normally, the energy distribution of speech signal is concentrated at the lower frequencies. If the energy of higher frequencies is relatively larger than of the lower frequencies the voice production is typically interpreted as as hyperfunctional. Vice versa, when the energy level of low frequencies is relatively large compared to high frequencies, the voice is interpreted as hypofunctional. Therefore, a gentle spectral tilt represents hyperfunction, and a steeper spectral tilt hypofunction. The reader of different studies must be careful when definitions of decreasing or increasing alpha ratio values are presented, because they rely much on the formula used. It is safer to concentrate on what the studies say about the skewness of the spectrum. The alpha ratio is usually measured from voiced speech segments, but it can also be measured from the long term average spectrum (LTAS; Löfqvist & Manderson, 1987).

In vocal loading studies, males have been found to have greater skewness after loading (Novak et al., 1991). In females, the findings have been the opposite. A statistically significant increase has been found in the energy content of the high frequency components during voice loading, which means that females' voice production has changed towards a more hyperfunctional production manner (Rantala et al., 1998b; Laukkanen et al., 2004).

4.2.4. Number of vocal fold vibrations

In order to investigate the effects of prolonged or excessive vocalization among voice professionals, it is important to quantify the amount of vocalization (Švec et al., 2003). Some studies have examined this by using different kinds of accumulators or dosimeters (more details in section 4.4.), which are usually designed to estimate the sound pressure level, fundamental frequency, and phonation time. For example, Masuda et al. (1993) found that the average speaking time for seven elementary school teachers was 103.6 minutes from a working day of 8 hours. This is 21.6% of the working day. In a study of ten healthy female preschool teachers by Södersten et al. (2002), the amount of phonation was 16.9% of the working day (6 to 8 hours).

To the best of the author's knowledge, the actual number of vocal fold vibrations has not been estimated in many studies. Vilkman (2004) has reported that during a working day a female teacher has about 1 million focal fold vibrations. Previously, Rantala and Vilkman (1999) and Rantala et al. (2002) have introduced the concept *index of voice loading*, which corresponds to the number of vocal fold vibrations. It was found that the more voice complaints the subject had the higher was the value of the index (Rantala et al., 2002). Thus, Vilkman (2004) has called for a discussion on expanding the idea of repetitive strain injury, that is understanding that the repeated movements of focal fold movements could be been as causing exertion at the level of vocal folds.

4.3. Glottal source analysis and parameterization

The basis of voiced sounds is the vibration of the vocal folds. During speech, the vibration of the vocal folds converts the air flow from the lungs into a sequence of short flow pulses. The resulting pulse train is called the glottal flow (see Figure 3) and the process of generating the voice excitation is called phonation. Speech sounds can be categorized in two classes based on if the vocal folds are vibrating. The periodical opening and closing of vocal folds produces voiced speech sounds whereas unvoiced phonemes are produced when vocal folds are not vibrating. Perceptually a voiced sound is defined as an utterance having a distinguishable fundamental frequency. Likewise, unvoiced sounds do not have any distinguishable fundamental frequency. For most West-European languages, voiced sounds constitute the most important category of phonemes. In English, for example, it has been estimated that almost 80% of phonemes are voiced (Catford, 1977).

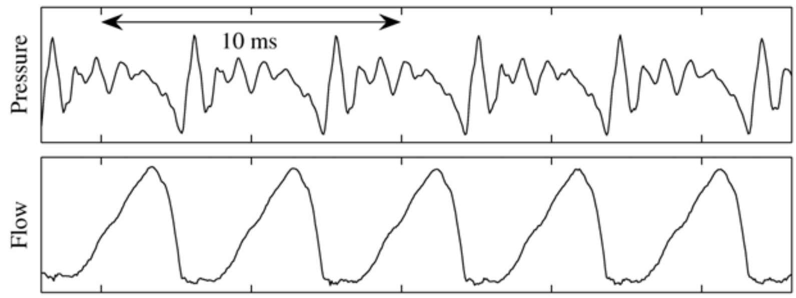

Figure 3: Speech pressure waveform of a female speaker's sustained /a/ vowel and the corresponding inverse-filtered glottal flow waveform.

Research on vocal fold functioning is an essential part of voice research. Vibratory characteristics of the vocal folds can be investigated using different methods. For example, image recordings of the larynx provide valuable information on the physiological movements of laryngeal structures during phonation. These research methods include videostroboscopy, high-speed imaging (e.g. Baer et al., 1983; Hertegård et al., 2003), and videokymography (e.g. Švec & Schutte, 1996). Imaging can be performed either via the nasal or oral cavity. These methods are, however, internal examinations of the larynx, and they prevent the subject from speaking naturally. Therefore, although they provide valuable information of vocal fold movements, their use in field examinations of occupational voice research is greatly limited. Some studies, though, have used stroboscopic examinations to evaluate the effect of voice loading in laboratory settings (Stemple et al., 1995; Gelfer et al., 1996; De Bodt et al., 1998; Roy et al., 2000).

To be able to study natural speech production, non-invasive research methods are required. One such non-invasive method to study vocal fold movements is electroglottography (EGG) (e.g. Baken, 1992). It describes vocal fold movements by measuring the impedance variations which are caused by the varying contact between the vocal folds. The EGG is measured during speech with electrodes placed across the subject's neck. However, the EGG requires production of long and stable vowels, and the stability of the electrodes on the neck is essential for succeeding in the measurement. Therefore, the use of the EGG in field examinations is limited and rather complicated. In order to monitor disordered voices, also accelerometers have been tested (Hillman et al., 2006). An accelerometer is an ambulatory monitoring system which is placed at the base of the anterior neck to sense phonation. It was generally demonstrated that accelerometer-based measures closely approximated corresponding measurements obtained from a microphone signal across all levels of dysphonia severity. There were not information how such an apparatus would be usable in field conditions.

Inverse filtering (Miller, 1959) is another non-invasive research method used in voice production studies. From recorded speech pressure waveform, it strives to estimate the pulsating air flow, the glottal velocity waveform, generated at the level of vocal folds. In principle, this is different compared to techniques which study the speech pressure waveform (presented in 4.2.). As the glottal waveform represents the glottal source function, it reflects the vibratory behaviour of the glottis and offers a straightforward possibility for parameterization of voice production. Therefore, it is a potential tool for describing loading changes in voice production (Vilkman et al., 1999) and is suitable for field examinations. In the following, inverse filtering (IF) and its applications in occupational voice research are described in more detail.

4.3.1. Acoustic theory of speech production

The contemporary understanding of vocal tract acoustics is based on a linear, time-invariant source-filter model (Kent, 1993). This is based on the pioneering work of Gunnar Fant, published in his book "Acoustic Theory of Voice Production" (1960). The source-filter concept assumes that voice production can be modelled by three separate processes: the glottal flow, the vocal tract, and the lip radiation. Even though Fant's model is a simplification of the real human vocal apparatus, it can be considered accurate enough for most speech sounds, especially vowels.

The filtering effects of the vocal tract are identified principally by its resonances. These resonances are called formants, and each formant is specified by a centre frequency (formant frequency, abbreviated F_n, where n is the formant number) and the bandwidth. They can be determined mathematically from a precise knowledge of the vocal tract shape, or they can be estimated from measurements of the acoustic signal. Formant frequencies vary with the length of the vocal tract and therefore with speaker characteristics, such as age and sex. Also, within sex, formant frequencies vary depending on the vocal tract dimensions each individual has (Kent, 1993).

4.3.2. Inverse filtering

The source-filter theory of speech production provides a theoretical basis for inverse filtering. An essential part of IF is the estimation of the vocal tract. When the vocal tract transfer function is known, the glottal excitation can be reconstructed by feeding the speech signal through the inverse of the vocal tract model. In practice, the transfer function of the vocal tract filter can be approximated, based on the speech signal and general knowledge about the voice production mechanism. The output of IF analysis is the estimate of the glottal volume velocity waveform, also known as the flow glottogram (FGG) (Hertegård et al., 1992; Hertegård & Gauffin, 1995).

Since the presentation of the idea of inverse filtering (Miller, 1959), many different versions of this technique have been developed. Inverse filtering methods can be divided into two categories, depending on the procedure that is used in recording the input signal. The first category consists of methods that are based on applying a specially designed pneumotachograph mask, the so called Rothenberg's mask (Rothenberg, 1973), in recording oral flow at the mouth (e.g. Holmberg et al., 1988;

Hertegård & Gauffin, 1991; Sundberg et al., 1993; Sulter & Wit, 1996; Sundberg et al., 2004). The second group of methods is based on processing the speech pressure waveform that has been recorded by a microphone in the free field outside the mouth (e.g. Price, 1989; Alku & Vilkman, 1996; Lauri et al., 1997; Vilkman et al., 1997; Vintturi et al., 2001a; Gobl & Chasaide, 2003).

A major part of the previous inverse filtering studies have used flow recordings. However, when measuring, for example voice loading changes throughout the working day in realistic situations, the use of a flow mask would be far too invasive and would therefore be impractical. In a comparison of inverse filtering from flow and microphone signals in 61 non-pathological subjects (16 males and 45 females), the results showed that the presence of a Rothenberg's mask used for the flow recordings had a significant effect on the parameters examined (Orr et al., 2003). These results might be explained by the subjects' inconsistent voicing strategies, a large variation in speech of the individual speaker, and the acoustic effects of the flow mask. Some studies argue that the flow mask offers a non-invasive possibility to measure air flow (Hillman et al., 1989; Holmberg et al., 1988). However, if voice measurements are to become a new routine as a part of occupational voice research, the psychological effect of the mask should also be taken into consideration.

4.3.3. Parameters used in inverse filtering

Analysis of voice production with inverse filtering comprises usually of two stages. In the first one, the estimates of the glottal flow (or its time derivative) are computed. The second stage of the analysis is the parametrization stage, which implies quantifying the obtained waveforms with properly selected numerical values. These quantities, the glottal flow parameters, aim to represent the most important features of the original flow waveforms in a compressed numerical form (Alku, 2003). In order to successfully quantify voice production with inverse filtering, one must know the different alternatives available in the parameterization stage and know on which features of the glottal flow these measures focus.

Many different methods have been developed for the parameterization (Alku, 2003). They can be categorized, for example depending on whether the parameterization is performed in the time domain or in the frequency domain. Time-domain methods include time-based parameters (quotients measuring critical time spans of the glottal pulse) and amplitude-based parameters (absolute amplitude values of the flow and its derivative) (see Figure 4). The most commonly used time-based parameters are open quotient (OQ), speed quotient (SQ), and closing quotient (ClQ) (Holmberg et al., 1988; Hillman et al., 1989; Dromey et al., 1992; Sulter & Wit, 1996; Lauri et al., 1997; Scherer et al., 1998). The amplitude-based parameters typically extracted are minimum the flow (also called the dc-offset), the ac flow, and the negative peak amplitude of the flow derivative (d_{min}), also called the maximum flow declination rate (MFDR) (Isshiki, 1981; Holmberg et al., 1988; Gauffin & Sundberg, 1989; Hillman et al., 1989; Sulter & Wit, 1996). The ac amplitude of the glottal flow has been found to correlate with SPL and also with the type of phonation, that is ac flow increased with raised loudness conditions (Holmberg et al., 1988; Gauffin & Sundberg, 1989). The negative peak amplitude of the first derivative of the glottal flow represents the main excitation of the vocal tract and is closely related to the SPL of the vocal output (Holmberg et al., 1988).

It is also possible to define time-based parameters from amplitude measures by using, for example the amplitude quotient (AQ) and its normalized version, the normalized amplitude quotient (NAQ) (Alku et al., 2002). The frequency-domain methods measure the spectral decay of the voice source and typically exploit information located at harmonics of the glottal flow spectrum. One of the most widely used parameters of this kind is the amplitude difference between the first and the second harmonics (H1-H2) (Kreiman et al., 1990; Sundberg et al., 2004).

In Studies 3 and 6 of this thesis, parameters NAQ, AQ, ClQ, H1H2 are investigated. All these parameters aim to present the effectiveness of the glottal function, which is of interest when performing research on voice fatigue. NAQ, AQ, ClQ and H1H2 all describe the level of steepness of the glottal waveform, as either time-based parameters (NAQ, AQ and ClQ), or as frequency domain features (H1H2). They can be used, for example to reflect changes on the axis of breathy to pressed phonation. Vintturi et al. (2001b) noticed increased AQ values after three hours of a voice loading task. ClQ and NAQ both have given smaller mean values for the pressed phonation, and larger values for the breathy phonation (Alku et al., 2002), and women with vocal training have found to have larger ClQ values compared to the untrained subjects (Sulter & Wit,1996). Training is assumed to result in using less adductory forces (i.e. less pressedness). This has also been noticed within the field of singing styles research (e.g. Sundberg et al., 2004). Also, H1H2 is related to the amount of roughness in the speaking voice (Kreiman et al., 1990).

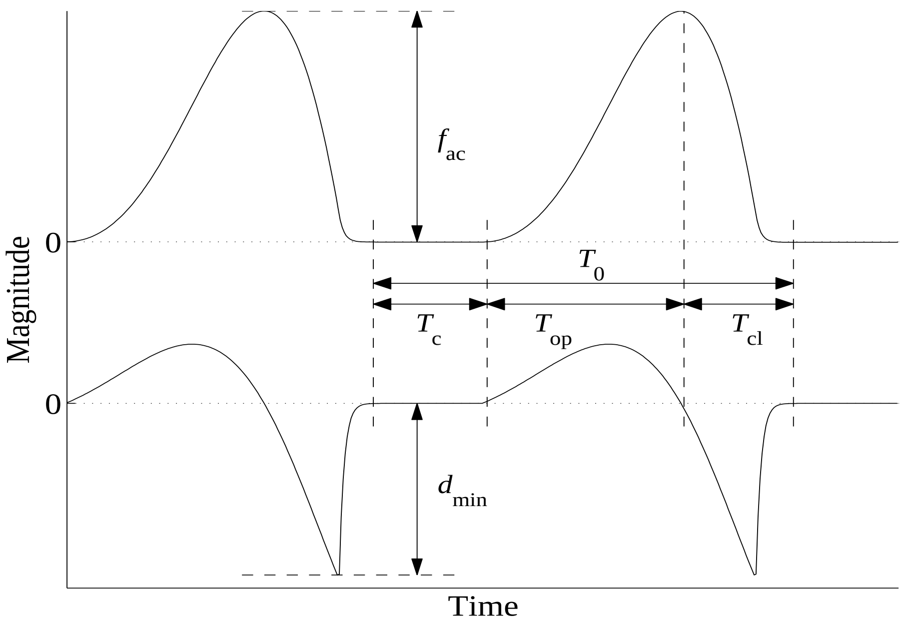

Figure 4: Schematic description of the computation of parameters ClQ, AQ and NAQ.

$$\mathrm{ClQ} = \frac{T_{cl}}{T_0} \quad \mathrm{AQ} = \frac{f_{ac}}{d_{min}} \quad \mathrm{NAQ} = \frac{\mathrm{AQ}}{T_0}$$

f_{ac} : maximal flow amplitude
d_{min} : negative peak amplitude of the flow derivative
T_0 : length of the glottal cycle
T_c : closed phase of the glottal cycle
T_{op} : opening phase of the glottal cycle
T_{cl} : closing phase of the glottal cycle

4.3.4. Inverse filtering in occupational voice loading studies

The previous use of inverse filtering in voice loading studies has so far been surprisingly sparse. To the best of the author's knowledge, inverse filtering has been previously performed in the following voice loading studies: Lauri et al., 1997; Vilkman et al., 1997; Vilkman et al., 1999; Vintturi et al., 2001a; Vintturi et al., 2001b. These studies will be reviewed in this chapter, regardless of the glottal flow waveform parameters they have used. All these articles have used data collected from the same research project, where the subjects were 80 normal healthy university students (40 females and 40 males) whose mean age was 22 years (range 18-45). All articles investigate at least some of the following glottal flow waveform parameters: time domain parameters OQ, ClQ, SQ, and amplitude domain parameters glottal flow (f_{ac}) and its logarithm, negative peak amplitude of differentiated flow (d_{min}) and its logarithm, AQ, and a parameter combined from AQ and ClQ, called CQAQ. The loading task in all studies was reading aloud a novel chosen by the subject. The length of each loading session was 45 minutes, and the experiment was planned to simulate a teacher's working day. The number of loading sessions and measurement times varied between studies. Some studies included special ergonomic and environmental factors.

In studies by Lauri et al. (1997) and Vilkman et al. (1999) two rest (morning and noon) and three loading (two in the morning and one in the afternoon) samples were recorded and analysed. All samples were produced with a soft, normal, and loud phonation style. In Lauri et al. (1997), the average OQ and ClQ values were lowest for loud phonation and highest for soft phonation for both females and males while SQ operated in the opposite way. In general, the changes were larger in females than in males. Lauri et al. (1997) hypothesize that the female voices tend to change towards hyperfunction due to voice loading. Vilkman et al. (1999) found that the values of d_{min} rose during loading and dropped due to rest in normal and soft phonation in females. The trends of males were not as systematic; the change was greatest in the morning, but for loud samples the d_{min} increased significantly also in the afternoon. The ac amplitude of the glottal flow (f_{ac}) always increased from soft to loud phonation. It was higher for males than for females at all loudness levels. Vilkman et al. (1999) point out that the voice changes due to vocal strain observed in a group of vocally untrained, healthy, young subjects can be interpreted as causing potential risks for vocal health in the long run. However, they remind that the changes were rather small.

In Vilkman et al. (1997), Vintturi et al. (2001a) and Vintturi et al. (2001b), the exposure groups consisted of eight combinations of the following environmental factors: 1) normal (<65dB) or high (>65dB) speech output level; 2) sitting or standing posture; and 3) low (25 +/- 5%) or high (65 +/- 5%) relative humidity of ambient air. The loading sessions were performed under these mentioned conditions. Two rest (morning and noon) and three loading (two in the morning and one in the afternoon) samples were recorded and analysed. All these analysed samples were produced with soft, normal, and loud phonation. Vintturi et al. (2001b) focused on studying the effect of a short vocal rest in the afternoon. The post-loading sample was recorded after three 45 minutes loading sessions with pauses of 15 minutes and a 45 minutes break after the last loading. The results showed that values of AQ and ClQ had increased and SQ had decreased during normal phonation. These differences reflect a shift towards softer phonation. In Vilkman et a. (1997), the high output loading resulted in the SQ in females to rise and the SQ in males to drop significantly. Vilkman et al. (1997) suggest that this might be a sign of compensation for vocal fatigue and a trend towards hyperfunction, whereas in males the SQ change may be due to increased stiffness of the vocal fold mucosa (i.e. an uncompensated loading change). In Vintturi et al. (2001a), the values of ClQ, AQ, and CQAQ in females decreased and the value of SQ increased during normal phonation; the values of f_{ac} and d_{min} increased during soft phonation, and values of AQ and CQAQ decreased during loud phonation. In males the values of OQ and AQ decreased and d_{min} increased during normal phonation; the values of f_{ac} increased during soft phonation. Also, Vintturi et al. (2001a) interpreted the changes as signs of a shift toward hyperfunctional voice production.

4.4. Voice analysis tools and environments

When measuring speech of occupational voice users, one line of research is to use different types of accumulators or dosimeters (Airo et al., 2000; Szabo et al., 2003; Popolo et al., 2002; Cheyne et al., 2003; Švec et al., 2005; Nix et al., in press). The accumulator software is usually designed to estimate SPL, F0, and phonation time. An accumulator measures the vocal dose on work tasks and other daily activities. In Watanabe et al. (1987) the accumulator was used for the first time in the research of voice-disordered patient. The device did not, however, measure the intensity of voice, which is seen as an important parameter underlying voice loading (Buekers et al., 1995). Heavy vocal load has been associated with voice intensities greater than 72 dB(A) (Buekers et al., 1995). Also a long phonation time and high intensities are factors leading to voice loading (Masuda et al., 1993). The drawback, however, when using this kind of a device is that it only stores the measured quantities but not the entire speech waveform. Therefore it does not allow later analyses of the voice samples.

The phonetogram presents the relationship between pitch and intensity in the voice during sustained phonation (Schutte & Seider, 1983). Therefore it is not practical in natural speech analysis in occupational voice-use situations. The phonetogram area have been found to be smaller with high background noise (Ternström et al., 2002). Some studies have used a phonetogram when measuring voice loading but the findings have not been significant (Ohlsson & Löfqvist, 1987; De Bodt et al., 1998). Also voice range profile (VRP) has been used in a vocal loading tests. The sound level averaged across the pitches was found to rise significantly during loading (Sihvo & Sala, 1996). When studying the effect of the so called warm-up in occupational voice users in different humidity conditions (Vintturi et al., 2001a), it was found that soft phonations are more difficult to produce after warm-up if the subject had been in the low-humidity conditions when measured with VRP. Vocal warm-up is defined as an initial period of rapid changes that takes place during voice loading.

To be able to measure voice features and describe them with parameters, the speech data collected are analysed in different speech analysis environments. The general heading of "voice analysis software" contains a broad range of different digital software packages. To mention a few, Key Elemetrics Corporations has developed the Multi-Dimensional Voice Program (MDVP) package, available for the Computerized Speech Lab (CSL) software. To study voice loading, MDVP has been used, for example in a study by Roy et al. (2000), but is more commonly used in investigating voices of dysphonic patients (e.g. Bhuta et al., 2004). Jonsdottir et al., (2002) have used the Lab-VIEW 2 graphical programming system (National Instruments), Schneider et al. (2006) the Healthlab hard- and software (SpaceBit GmbH). In Södersten et al. (2002), a custom-made computer program Aura (Granqvist, 2001) was used in order to analyse binaural recordings with two channels.

In this thesis, the voice analysis program Puhetauko was used in two studies (Studies 3, 4 and 5). Puhetauko is a speech analysis environment for continuous speech (Bäckström, 2001), developed from a speech analysis environment (Haataja, 1993) based on analog measurements of voice quality parameters. Bäckström (2001) updated and replaced this analysis environment with a digital analysis environment. The new environment implementation is based on modern signal processing techniques, which are made possible by the availability of high-speed processors and large memory capacity which today's computers supply compared to the 1990's. The current version of the Puhetauko program can analyse up to five-minute recordings of speech at a time. It classifies the input signal into silence, voiced speech and unvoiced speech, and the number of vocal fold vibrations can be calculated by multiplying the voiced speech time by the F0. Puhetauko determinates parameters F0, SPL, and AR from voiced speech segments from the five minutes analysis time.

5. SUMMARY OF PUBLICATIONS

This thesis comprises of six publications, all published in international peer-reviewed journals. All the publications are related to the research of occupational voice problems and the underlying speech analysis methodologies. Originally, the initiative to gather the data studied in this thesis (studies 1 to 5) came from the largest Finnish telecommunications operator Sonera (currently known as TeliaSonera Finland Oyj) in an effort to gain knowledge about the voices of their call-centre personnel. Studies 1 and 2 report the amount of self-reported voice problems of telephone customer service advisors (CSA). Also, the effects of a voice training program are investigated. Study 3 presents results of both subjective (voice complaints) and objective (acoustic voice analyses) changes during a working day of CSAs. Study 4 investigates the correlation between these subjective and objective measures. Studies 1 to 4 involved the same subjects, represented by employees of the Sonera customer service call-centre, Kuusamo, Finland. Study 5 presents and tests an analysis environment for the continuous speech used in Study 3. Study 6 addresses a widely used voice production analysis tool, inverse filtering. Inverse filtering, also used in Study 3, is analysed in Study 6 by running a comparison between a manual and a semi-automatic algorithm.

[Study 1]

Lehto L, Rantala L, Vilkman E, Alku P, Bäcktröm T, ”Experiences of a short vocal training course for call-centre customer service advisors.”, *Folia Phoniatrica et Logopaedica*, 2003; 55: 163-176.

The purpose of this study was to find out the effects of a short (two days) vocal training course on professional speakers' voice. The subjects were 38 female and ten male customer advisors, who mainly use the telephone during their working hours at a call-centre. The results showed that although the subjects did not suffer from severe voice problems, they reported that the short vocal training course had an effect on some of the vocal symptoms they had experienced. Five weeks after the training more than 50% of the females and males reported a decrease in the feeling of mucus and the consequent need to clear the throat, and a decrease in the worsening of their voice. Over 60% thought that voice training had improved their vocal habits, and none reported a negative influence of the course on their voice. Females also reported a reduction of vocal fatigue. The subjects were further asked to respond to 23 statements on how they experienced the voice training in general. Both females and males agreed to a high degree especially with statements like "I learned things that I didn't know about the use of voice in general" and "I got useful and important knowledge concerning my work". The results suggest that even a short vocal training course might affect positively the self-reported well-being of persons working in an occupation where voice is the main tool of the trade.

[Study 2]

Lehto L, Alku P, Bäcktröm T, Vilkman E, "Voice symptoms of call-centre customer service advisors experienced during a work-day and effects of a short vocal training course", *Logopedics Phoniatrics Vocology*, 2005; 30(1): 14-27.

The target of this study was to investigate the amount of voice symptoms of call-centre customer service advisors four times during a working day and to find out the long-term effects of a short (two days) vocal training course. The subjects of this study consisted of 35 females and ten males, whose work involves exclusively answering customer calls during the entire working day. The results showed that although self-reported voice problems were not severe, they increased during the working day. The subjects' general opinions about the vocal training course were very positive. They felt they had gained useful and important knowledge concerning their work, and had attained new knowledge about voice production. There was still a persistent increase in subjective symptoms throughout the working day even after the training program. However, in females there was a decrease in most symptoms after the training, but in males some of the symptoms increased after the training and also in the follow-up study. A comparison of the sum variables of the symptoms before and after the training program showed that in females the vocal strain and hoarseness had diminished significantly. One and a half years after the training, there were no significant changes compared to the situation five weeks after the training. Therefore, it can be concluded that female subjects gained long-term benefits from the training. The small number of male subjects, unfortunately, does not allow making strong conclusions on the effects of training on male voice users. However, the limited data available tentatively indicates that males might not benefit from vocal training as much as females. However, the results suggest that preventive voice care should be emphasized as a tool to sustain occupational capacity.

[Study 3]

Lehto L, Laaksonen L, Vilkman E, Alku P, ”Changes in objective acoustic measurements and subjective voice complaints in call-centre customer service advisors during one working day”, accepted for publication in *Journal of Voice*.

The aim of this study was to investigate how different acoustic parameters, extracted both from speech pressure waveforms and glottal flows, can be used in measuring vocal loading in modern working environments and how these parameters reflect the possible changes in the vocal function during a working day. In addition, correlations between objective acoustic parameters and subjective voice symptoms were addressed. The subjects were 24 female and eight male customer service advisors, who mainly use the telephone during their working hours. Speech samples were recorded from the continuous speech four times during a working day and voice symptom questionnaires were completed simultaneously. To study the glottal flow, a vowel segment from a starting phrase cut from continuous speech was investigated. Among the various objective parameters, only the fundamental frequency resulted in a statistically significant increase for both genders. No correlations between the changes in objective and subjective parameters appeared. However, the results encourage researchers within the field of occupational voice use to apply versatile measurement techniques in studying occupational voice loading.

[Study 4]

Lehto L, Laaksonen L, Vilkman E, Alku P, “Occupational voice complaints and objective acoustic measurements – Do they correlate?”, *Logopedics Phoniatrics Vocology*, 2006; 31(4): 147-152.

The study was performed in order to find connections between subjective voice complaints and objective observations on voice to enable the development of appropriate diagnostics and treatment for occupational voice disorders. The subjects were 24 female customer service advisors (CSAs), who mainly use the telephone during their working hours. During one working day, at four different times, speech samples covering 20-minute telephone conversation by the CSAs were recorded. In addition, the CSAs filled in a questionnaire concerning their voice problems. Vocal symptoms were represented by three variables: vocal fatigue, hoarseness, and a general sum-variable. A five minute sample was taken from recordings for further analyses. This included the fundamental frequency, sound pressure level, alpha ratio (the ratio between the spectral energy below and above 1000 Hz), and number of vocal fold vibrations. In the objective acoustic measurements, it was found that the fundamental frequency rose significantly during the working day. Also, the self-reported voice symptoms increased significantly during the working day. However, correlations between vocal symptoms and acoustic measures were not found.

[Study 5]

Bäcktröm T, Lehto L, Vilkman E, Alku P, ”Automatic pre-segmentation of running speech improves the robustness of several acoustic voice measures”, *Logopedics Phoniatrics Vocology*, 2003; 28(3): 101-108.

In order to study vocal loading, an effective speech analysis environment for continuous speech is needed. The goal of this study was to describe such a robust system capable of handling large amounts of data while minimizing the amount of user-intervention required. The current version of the system can analyse up to five-minute recordings of speech at a time. Through a semi-automatic process it will classify a speech signal into segments of silence, voiced speech, and unvoiced speech. Parameters extracted from the input signal include fundamental frequency, sound pressure level, alpha-ratio, and speech segment information such as the ratio of speech to silence. This study also presents results from the performance evaluation of the system. The analysis environment was found to be able to perform as a robust and consistent measurement tool for continuous speech.

[Study 6]

Lehto L, Airas M, Björkner E, Sundberg J, Alku P, "Comparison of two inverse filtering methods in parameterization of the glottal closing phase characteristics in different phonation types", *Journal of Voice*, 2007; 21(2): 138-150.

Inverse filtering (IF) is a common method used to estimate the source of voiced speech, the glottal flow. This investigation aimed to compare two IF methods: one manual and the other semi-automatic. Glottal flows were estimated from speech pressure waveforms of six female and seven male subjects producing sustained vowel /a/ in breathy, normal, and pressed phonation in laboratory conditions. The closing phase characteristics of the glottal pulse were parameterized using two time-based parameters: the Closing Quotient (ClQ) and the Normalized Amplitude Quotient (NAQ). The information given by these two parameters indicates a strong correlation between the two IF methods. The result of the present study can be considered encouraging in showing that automatic IF can be developed in the future to meet the needs of extensive speech data analysis.

6. CONCLUSIONS

A voice disorder from an occupational point of view exists if the individual's voice does not meet the occupational criteria and demands (Vilkman, 2004). In addition, all complaints of voice fatigue, voice symptoms, and voice problems (even if not diagnosed as a disorder) should be taken equally seriously in order to sustain the capacity and well-being of those using voice as the main tool of their trade. Towards this perspective, the aims of this thesis were to investigate the voice problems of call-centre customer service advisors and to study if they benefit from preventative voice training. Another aim was to investigate how changes in voice could be measured objectively from acoustic waveforms during a working day in realistic work environments and situations, with special emphasis on inverse filtering.

Call-centre employees experienced voice symptoms to some extent and the amount of these symptoms increased during the working day. However, the general degree of voice problems was not serious. The reasons underlying this finding might be the young age of the employees (mean 28 years), their short career (mean working experience approximately one year), and the acoustically well-designed open-plan office with low background noise level (no need to raise ones voice). However, both in Finland and world-wide there are most likely such (open-plan) offices where the conditions are not as good as in the one studied in this thesis. It can be assumed that speech communication environments are poor in many offices and that many telephone employees are subject to loading to a greater extent as indicated by the study of Jones et al. (2002). Therefore, the results of this thesis are not to be generalized for all call-centres, and further studies are undoubtedly needed to get a thorough understanding of reasons behind voice problems in telephone work.

The preventative voice training program was found to be useful. Both the short- and long-term results suggested that even a short vocal training program can have a positive effect on the symptoms experienced by employees, particularly female, working in occupations with extensive use of voice. This was in spite of the fact that Studies 1 and 2 showed that the call-centre customer service advisors suffered from relatively low level of voice symptoms. However, even these voice symptoms decreased significantly due to the training course.

In studying voice objectively from speech samples recorded in realistic work environments and communication situations, the program Puhetauko was found to be a robust system in being able to calculate acoustical parameters from running speech. Only the fundamental frequency resulted in a statistically significant change during the working day. Previously, studies in occupational voice workers have shown the acoustical features to change due to voice loading (Stemple et al., 1995; Vilkman et al., 1999; Rantala et al., 2002; Södersten et al., 2002; Ternström et al., 2002; Laukkanen et al., 2004; Schneider et al., 2006). The underlying reasons for minor acoustical changes in the present call-centre might be due to, for example, the fact that the acoustical environment did not make the employees raise their voice level (compared to noise levels in schools and day care centres; Sala et al., 2002; Södersten et al., 2002). In addition, speaking situations in telephone customer service are closer to a dialogue than a monologue, which is different from, for example, the teaching speech. Therefore, employees have a chance for short-term recovery during calls and this might help them to preserve their voice function (Yiu & Chan, 2003). However, it is important to remember that on a phone the speaker must rely solely on his/her voice. This makes speaking on a telephone a more challenging work than occupations in which employees can have support from body language or written communication.

To the best of our knowledge, the present thesis is the first one which has studied inverse filtering performed on samples recorded from running speech in a realistic occupational environment in natural speech communication situations. Analysis was conducted over a short vowel segment from a standard starting phrase. The estimated glottal flows were, in general, reliable and similar to those obtained in laboratory settings from sustained phonation hence indicating that inverse filtering is possible to be computed successfully under these conditions. In the future, however, inverse filtering is recommended to be computed over several vowel segments during speech. In addition, we studied a manual and a semi-automatic inverse filtering method. A high correlation was found which suggests inverse filtering to have potential in extensive speech data analysis. In addition, we experimented with a manual and a semi-automatic inverse filtering method. Comparison between the methods yielded consistent results thereby giving positive evidence of the performance of IF in the objective analysis of vocal function.

Altogether, the information obtained in this thesis shows that prolonged voice use can result in vocal symptoms even in the case of good environmental factors. Preventative voice training constitutes an efficient method to decrease voice symptoms. Speech samples collected from natural working environment in real speech communication situations can be used successfully in objective acoustical analysis. In addition, estimation of the glottal excitation with inverse filtering is informative from the point of view of occupational voice research.

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