VALDÍS INGIBJÖRG JÓNSDÓTTIR

The Voice
An Occupational Tool

A Study of Theacher´s Classroom Speech and the Effects of Amplification

■

ACADEMIC DISSERTATION
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I dedicate this thesis to all those who work to increase our knowledge of the voice and how to look after it.

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ERRATA

(1) Numbering of the following sections is erronous:
2.3.2. should be 2.3.1.1.
2.3.3. should be 2.3.2
2.3.3.1 - 2.3.3.6 should be 2.3.2.1 - 2.3.2.6
2.3.4 should be 2.3.3
2.3.4.1 should be 2.3.3.1
5.2.4.2 - 5.2.4.3 should be 5.2.3.2 and 5.2.3.3

(2) 5.2.4 and 5.2.4.1 repeat the previous sections and should, thus, be omitted

(3) Some names have been misspelled and should be as below
page 7, Article I: (Irma) Ilomäki
Article V:Ilona (Siikki)
page 32, section 2.2.9.1, 2nd paragraph, first line from top: Jiang
page 90, reference 148: Haataja
page 93, ref 186: Scherer
page 95, ref 206: Sihvo

(4) Some words have been erronously left out
page 18 lines 6 - 7 from top: 'factors'
page 23, last sentence from bottom: 'resonance'

(5) Some words and numbers should be replaced
page 52, 2nd paragraph, 2nd line from top: instead of 'these' should be 'certain'
page 63, section 5.2.3.1, 3rd line from bottom: 'Intra-observer' should be 'Inter-observer'
page 64, section 5.2.4.2 (which should be 5.2.3.2), 3 rd line from top,'p = 0.100' should be 'p = 0.08'

(6) One paragraph is incorrectly placed:
page 20 , section 2.2.3, first paragraph: last sentence should be the last sentence in the previous section.

(7) Printing errors and alike, should be corrected as follows
page 44, 3rd paragraph from top, 2nd line from top: improvement of
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page 63, fig 8 , title: student**s**
page 75, section 6.3.4 (should be 6.3.3), title: the

ABBREVIATIONS

AC flow	Alternating current or the pulsating airflow
AQ	Amplitude quotient
CQ	Closed quotient (closed time divided by the length of the fundamental period)
ClQ	Closing quotient (time interval from maximum flow to the start of the glottal closure divided by length of the fundamental period)
d_{peak}	Negative peak amplitude of the differentiated glottal flow
dB	Decibel
f_{AC}	Glottal AC- flow
F0	Fundamental frequency
F0 time	Phonation time
Hz	Herz
ISA	Intelligent Speech Analyser (Speech analysis system, developed by Raimo Toivonen, M.Sc.Eng.)
LTAS	Long-term-average-spectrum
p	(Air)pressure
OQ	Open quotient (the ratio between the duration of the open phase of the glottal cycle and the length of the fundamental period)
RASTI	Rapid Speech Transmission Index
RT	Reverberation time
S/N	Signal-to-Noise ratio
SPL	Sound pressure level
SQ	Speed quotient (the ratio between the duration of the glottal opening and the closing phase)
T	Length of the fundamental period
VAS	Visual Analogous Scale
WIPI	Word Intelligibility by Picture Identification

LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following original studies which are referred to in the text by their Roman numerals.

I. Valdís Jónsdóttir, Anne-Maria Laukkanen, Irma Ilomäki, Heidi Roininen, Merja Alastalo-Borenius, Erkki Vilkman: Effects of amplified and damped auditory feedback on vocal characteristics. Logopedics Phoniatrics Vocology, 2001; 26:2:76-81.

II. Valdís Jónsdóttir, Leena Rantala, Anne-Maria Laukkanen, Erkki Vilkman: Effects of sound amplification on teachers' speech while teaching. Logopedics Phoniatrics Vocology, 2001; 26:3:118-123.

III. Valdís Jónsdóttir: Cordless amplifying systems in classrooms. A descriptive study of teachers' and students' opinions. Logopedics Phoniatrics Vocology, 2002; 27:1: 29-36.

IV. Valdís Jónsdóttir, Anne-Maria Laukkanen, Erkki Vilkman: Changes in teachers' speech during a working day with and without electric sound amplification. Folia Phoniatrica et Logopaedica, 2002: 54: 6: 282-287.

V. Valdís Jónsdóttir, Anne-Maria Laukkanen, Ilona Siikki: Changes in teachers'voice quality during a working day with and without electric sound amplification. Folia Phoniatrica et Logopaedica, 2003: 55:5:267-280.

SUMMARY

Teachers are professional voice users who experience a high risk of developing voice problems and, indeed, voice problems are common among teachers world-wide. Their unfavourable working conditions are identified as the principal reason for voice problems: they are often required to teach in large classrooms with poor acoustics, background noise and at too great a distance from some of their pupils. These same circumstances create in their turn unfavourable listening conditions for pupils: the teacher's voice cannot be heard sufficiently well throughout the classroom and because of the unsatisfactory signal-to-noise ratio the speech content cannot be clearly perceived against the level of background noise. For the teacher, such teaching conditions tend to result in strenuous phonation with raised sound pressure level (SPL) and fundamental frequency (F0) and more hyperfunctional voice production with stronger collision forces between the vocal folds. This means that more loading is imposed on the vocal folds during vibration. If vocal loading is sustained over long periods it can lead to vocal fatigue (which evidences itself in poorer voice quality, e.g., cloudiness and roughness), or even to pathological changes in the vocal fold tissue.

This study addressed one possible solution which may serve to improve teachers' vocal ergonomics and pupils' and students' listening conditions - the use of electric sound amplification in the classroom.

AIMS

This study was designed to a) investigate the effects of amplification on the vocal parameters of teachers' voices in classroom and b) collect data on students' and teachers' opinions on amplification.
Six questions were addressed:

1. Does amplified or damped (i.e. reading with ear plugs) auditory feedback lower the average F0 and SPL in text reading? (Study I)

2. Does the use of amplification lower F0 and SPL of the teacher's classroom speech? (Study II)

3. (a) Is there a change in vocal parameter values or in perceptual voice quality during a teacher's working day? (b) Is this change different when amplification is used in classrooms? (Studies IV and V)

4. Does the use of amplification in classrooms diminish the teachers' symptoms of vocal fatigue? (Study III)

5. Does the use of amplification in classrooms make it easier for pupils to listen to the teaching? (Study III)

6. What other advantages and disadvantages of the use of amplification in classroom will be reported by the teachers and students? (Study III)

SUBJECTS AND METHODS

STUDY I (a laboratory study). Six females without any known voice or hearing problems read aloud a text that consisted of 133 words containing no /s/ phoneme. The subjects read the text aloud twice under normal conditions and then twice while hearing their own voices amplified through headphones (the level of amplification was held constant).

A damping test was carried out two to six months after the amplification test. The scheme was the same as in the amplification test except the subjects now read the text aloud wearing foam plastic earplugs.

The reading samples for both amplification test and damping test were recorded six times on three days (once every morning or midday and once in the afternoon or evening). Recordings were analysed for F0 and SPL (both total SPL and SPL at given frequency ranges) with a signal analysis system called Intelligent Speech Analyser (ISA), developed by Raimo Toivonen, M.Sc.Eng.

STUDY III. Thirty-three teachers (26 females and 7 males with teaching experience ranging between 1 and 32 years) participated voluntarily with their students from three Icelandic educational levels - the basic school system (for children 6 – 15 years in age), a junior college (for students 16 – 20 years in age) and a university. In total, 791 students (446 females and 345 males) participated. The teachers used amplification in class for at least a week. The wireless equipment consisted of a Lavalier (chest borne microphone) with transmitter and receiver. A portable loudspeaker was used by all but two of the subjects, who used loudspeakers fastened to the wall. The transmitter was battery-powered, while the rest of the equipment was powered through the mains.

At the end of the research period the teachers answered two questionnaires. One, with 19 multiple-choice questions, was designed to elicit background information. The other one, with 13 multiple-choice questions, was designed to obtain their opinions on the advantages and disadvantages of using amplification in class. Students aged 10 years and older (n=664) received a multiple-choice questionnaire about the advantages and disadvantages they experienced when their teachers were using amplification in class. In all these questionnaires the respondents were required to choose from the alternatives ‘considerable - some - little - nothing’.

Students aged 6 - 9 years (n=127) were asked two questions: (1) Did you like it when your teacher used an amplification system? (2) Why?

STUDIES II, IV,V (field studies). Five teachers (three females and two males; mean age 51 years), all with long teaching experience, volunteered themselves from the group of 33 teachers who took part in Study III. All suffered from multiple vocal symptoms (3 or

more symptoms) that occurred principally during the term. A clinical examination of each subject was performed before the experiment started. No pathological changes were found. Background information was gathered with a questionnaire. The subjects' classroom speech was recorded on a portable battery-operated DAT recorder. The recordings took place in the first and last lessons of the working day which the subjects had chosen as being the most difficult on their timetables; the samples were taken first without amplification and then a week later with amplification (the teachers having used the amplification system for the whole of that week). Samples lasting from two to four minutes were taken for analysis from the very beginning, from the middle, and from the end of each lesson.
For Study II, the variables analysed were average F0, SPL and phonation time.
For Study IV, F0 and SPL were analysed. F0 and SPL were measured with an analogous system (F-J electronics) and analysed with a micro-computer.
For Study V, spectral changes were studied with ISA and the voice quality was evaluated by two professional voice trainers.
In all studies a comparison was made between the vocal characteristics of unamplified and amplified speech.

RESULTS

STUDY I. Both amplified and damped auditory feedback led to a significant decrease in F0 and SPL values (Student's t-test). Additionally, amplified feedback was associated with 1) lower alpha ratio and 2) a decreased level difference between the ranges of F1 and F0 when compared with unamplified feedback.

STUDY II. Amplified auditory feedback in the classrooms led to a statistically significant decrease in the average F0 and SPL (Student's t-test). Amplification did not significantly affect phonation time.

STUDY III. The majority of teachers and students found amplification beneficial and the few disadvantages mentioned were mainly technical problems, frequently due to a lack of knowledge of how to use the equipment. With amplification teachers found it easier to talk and experienced less fatigue in the vocal apparatus. Students found it easier to hear the teacher through class chatter and easier to follow the lesson.

STUDY IV. F0 and SPL increased on average during the teachers' working day both with and without amplification. The increase was larger and for F0 statistically significant when amplification was used. Correlation was found between F0 and SPL both in ordinary and amplified conditions. Relatively large changes were found in F0 during the lesson.

STUDY V. The slope of LTAS was steeper and SPL lower when amplification was used. When amplification was used the slope decreased significantly and SPL rose during the working day. The two male subjects showed somewhat different results from the females. The spectral tilt in the male voices decreased less compared to the female voices or even increased at some ranges during the day when amplification was used. In perceptual evaluation the overall voice quality was identified as better when amplification was used.

CONCLUSIONS

Both teachers and pupils agreed that amplification in classroom was beneficial, and the results suggested that amplification in class may be ergonomically desirable both for teachers' voices and for students' listening effectiveness.

Amplified auditory feedback significantly lowered F0 and SPL and the spectral slope became steeper, both in laboratory and in classrooms, which indicates less strenuous voice use. When compared with unamplified lessons, the fundamental was relatively stronger and the overtones were weaker, indicating softer collision of the vocal folds and, consequently, less stress imposed on the vocal folds. The results from damped auditory feedback showed also a significant decrease in F0 and SPL and in this case F0 decreased relatively more than SPL when compared to the effects of amplified auditory feedback. It should be noted that dampening effects from earplugs may cause the voice to sound darker. Voices with darker timbre tend to be heard as lower in pitch and this may therefore have caused a larger decrease in pitch.

Average F0 and SPL increased and the spectrum slope became less steep during the teachers' working day both with and without amplification; the increase was greater when amplification was used. It has been hypothesized that a sufficient vocal loading-related rise in F0, SPL and decrease in spectrum slope show the vocal organ's ability to adapt adequately to vocal loading. The use of amplification may therefore indicate that the vocal organs are undergoing adaptation to vocal loading. It can result from increased activity in the respiratory and laryngeal muscles or it may reflect decreased tissue viscosity. In contrast, a negligible rise or fall in these vocal parameters could be a sign of vocal fatigue. No significant change was seen in phonation time. As the subjects felt less vocal fatigue when using amplification the increase in F0 and SPL and decreased spectral tilt may be interpreted not as a sign of vocal fatigue but rather a reflection of a normal adaptation to loading. It could also suggest that the subjects were more tolerant of an increase in these parameters during the day as the F0 and SPL were lower when using amplification.

In unamplified lessons no significant changes in spectrum were observed and more vocal fatigue was experienced. Therefore, a hypothetical interpretation is that there was inadequately high muscle tension in the vocal apparatus right from the beginning of the working day. The results were more prominent in females, suggesting that there may be possible gender-dependent differences in loading-related changes in vocal parameters that warrant further investigation.

The voice quality was perceived better in the amplified situation, pointing to a less strained voice use. However, the apparent strain increased during the working day, which is in accordance with the larger decrease in spectral tilt. In general, perception of various vocal characteristics correlated in a rational way with changes in the spectrum. Overall voice quality correlated positively with increased spectral tilt, which is in contrast to earlier findings showing that a good speaking voice quality was characterized by a less steep spectral slope. The reason could be that the voice samples in this study were not taken from voice use at habitual conversational volume but from speech in the classroom, where teachers were required to project their voices. All voices in the present study were perceived as more or less strained and the quality was regarded as good in none of the samples. The reason may be that all these teachers had long teaching experience in an environment known to be harmful to the voice.

1. INTRODUCTION

1.1. THE VOICE AS AN IMPORTANT BUT VULNERABLE FACTOR IN TEACHING EFFECTIVENESS

To ensure effective communication, it is important that:
a) teachers are able to communicate with their students without endangering their voices and b) the students are able to hear what the teachers are saying without too much difficulty. These two factors must certainly go hand-in-hand if teaching is to show good results. Unfortunately, the classroom environment, where there is often too much noise and where long distances are frequently imposed between teachers and learners, places the teacher's voice at risk of damage and makes it difficult for many of the students to hear the teacher properly.

In spite of modern innovations in teaching methodology, the voice remains the most important working tool of the teacher: “It is a sine qua non that an audible and durable voice is a prerequisite of oral teaching” (Ohlson, 1988, p112). According to Borden and Harris, 1984 (p159): “The goal of the speaker is to produce sounds that fit an auditory perceptual target in order to be understood by the perceptual system of a listener”. Factors which can prevent the teachers’ orally delivered information and instruction from reaching the ears of the learners may be of physiological, psychological or environmental origin, or a combination of all these factors, and may originate either with the teacher or the learner, or both.

Teachers are one of the largest groups of professional voice users: e.g., in the USA they are the second largest group after salespersons (Titze et al., 1997), in Finland the third largest group after foremen and salespersons (Laukkanen, 1995) and in Sweden the third largest group after salespersons and health care professions (Fritzell, 1996). Of all occupations, those engaged in teaching are considered to be the most at-risk of incurring voice problems (Verdolini and Ramig, 2001; Vilkman, 2001). Twenty to eighty percent of teachers have, according to several research questionnaires, reported that they suffer from various vocal symptoms, the most common of those being dryness in the throat and vocal fatigue, considered to be due to prolonged voice use while teaching (e.g., Russel and al., 1998; Sapir et al., 1993; Gotaas and Starr, 1993; Pekkarinen et al., 1992; Ceuppens, 1995; Smith et al., 1997). Indeed, Swedish research results suggest that the teachers are the largest group of professionals seeking medical help for vocal symptoms (Fritzell, 1996). Unger and Bastien (1981) and Herrington et al. (1988) also found teachers prominent amongst those seeking medical help for voice problems.

According to questionnaire responses from 189 teachers and 91 controls (Morton and Watson, 1998) temporary illness associated with voice problems is considerably more common amongst the teachers than amongst the controls. Additionally, research findings have suggested that between one fifth and one third of teachers are absent from work as a result of voice problems during a working year (Smith et al., 1997; Sapir et al., 1993). It is calculated that in the USA these societal losses due to voice disorders in teachers cost about $2.5 billion annually (Verdolini and Ramig, 2001). It is therefore clear that we are talking about an occupational health issue which affects both the individual and the society in general.

In the questionnaire research by Smith et al. (1997), half of the teachers indicated that they were currently hoarse in comparison to one fifth of the control subjects. In a questionnaire study, the most frequently cited symptoms in 274 male and 280 female teachers were hoarseness, a fatigued voice and discomfort when speaking loudly (Smith et al., 1998 (a)). In classroom conditions a hoarse and low-pitched voice or a soft, asthenic voice makes it difficult for the students to hear the teacher.

It is rather common to attribute vocal symptoms such as hoarseness to teachers' misuse of their voices. However, this can be misleading as it gives the impression that teachers have some choice in the matter. It would be more accurate to say that teachers are forced into strenuous prolonged voice use because of unfavourable environmental, physiological and psychological factors, each of which can be harmful to the voice. If we look at the problem from this angle, we are talking about occupational hazards, factors inherent in the working environment and the nature of the profession. “As to the risk factors, the main hazard can be considered to be prolonged use of the voice itself” (Vilkman, 2001). The condition of the voice of these professional voice users is serious and detracts from the individual's ability to work in a normal way. In consequence, the Voice Commission of the Union of European Phoniatricians (UEP) and Pan-European Voice Conferences (PEVOC) recently set up a study programme concentrating on voice as an occupational safety and health (OS&H) issue. The results strongly indicated that the OS&H situation of voice and speech professionals is poor in Europe (Vilkman, 2001). It is clear that the voice has still not received recognition as an occupational tool to which employers must give care and attention. “For some reason these professions are not understood in the same basic terms as other professions” Vilkman (2001). Sala et al. (2002) indicate certain difficulties in having voice disorders specified as an occupational disease; they do not fall directly within the usually accepted definition of what constitutes an occupational disease i.e. a disease the primary cause of which is exposure at work to causal factors of either a physical or a chemical nature.

As far as teachers are concerned, study results have shown that voice problems are common among teachers world-wide (Russel et al., 1998; Sapir et al., 1993; Gotaas and Starr, 1993; Morton and Watson, 2001; Comins, 1992 and 1995; Pekkarinen et al., 1992; Smith et al., 1997; Ceuppens, 1995; Vilkman, 1996; Vilkman, 2000; Verdolini and Ramig, 2001, Titze et al., 1997). In the case of students, results have shown that the educational environment leaves a great deal to be desired. Research results have indicated that the signal to noise ratio (in this instance the teacher's voice measured against the background noise in the classroom) does not reach recommended levels for young or handicapped listeners (15 dB) (Sanders, 1965; Crandell and Smaldino, 1995 (a and b); Finitzo - Hieber, 1988; Leventhall, 1998) and the distance from the teacher may be too great to allow the students to hear clearly the teachers’ instructions (Leavitt and Flexer, 1991; Crandell and Smaldino, 1994; Crandell and Bess, 1986). For the sake of teachers' voices and for pupils' ability to hear, there is a need for considerable ergonomic improvement in the average working classroom. Consequently, in this preliminary study teaching effectiveness has been investigated from the point of view of the teacher's voice and the learners' ability to hear.

2. REVIEW OF THE LITERATURE

2.1. EFFECTIVE COMMUNICATION IN CLASS

Whatever may be the impact of modern technology on teaching methods in the future, it is a fact that up till now teachers have relied on the unaided use of the human voice to transmit information and instructions from teacher to learner. An audible and durable voice, a satisfactory acoustic environment and an appropriate distance between the listener and the speaker are fundamental to all successful lessons.

2.1.1. Teachers' effectiveness: the role of the voice

Schmidt et al. (1998) have examined teachers' overall effectiveness using perceptual and acoustic measurements from voice samples. Acoustic analyses were carried out from 200 voice samples for each of 7 teachers performing a 10-12 minute lecture. A perceptual evaluation was provided by 180 undergraduate and graduate students. The results indicated that the greater the frequency range and the frequency variability, and the lower the rate and number of dysfluencies, the more effective was the teacher considered to be.

Some research results have indicated that students form unfavourable views of the speakers when they find their voices unpleasant to listen to (Blood et al., 1979; Wanser and McCroskey, 1998; Lallh and Rochet, 2000) In those study designs the listeners listened to the voice samples without being able to see the speaker. It would have been interesting to see whether the conclusions would have been different if they had done so. Wanser and McCroskey (1998) studied the effects of the teachers' socio-communicative style on the students' opinions on the teacher and the learning material. They concluded that first and foremost "students desire lecture material which they can understand and hear". According to this it would appear that the attractiveness of a teacher's voice is not a major factor when considering teaching effectiveness. However, up till now surprisingly little attention has been paid to the importance of teachers' voice quality and voice capacity in communicational and audiological research on effective teachers' behaviour in class.

It is undeniable that voice problems can impair a teacher's working efficiency. In a questionnaire-based research into the impact of voice problems on the quality of life, half of the 174 patients seeking treatment for voice problems stated that their problems had negatively affected their past (53%), current (49%) and future (76%) working abilities (Smith et al., 1996). Indeed, the more acute the voice problems are, the more seriously they detract from the patients' quality of life (Jacobson et al., 1997).

2.1.2. Students' ability to hear

Effective listening requires the ability to hear (i.e. normal hearing or adequate artificial compensation for it), good acoustics in the classroom, an appropriate distance between teacher and learners, an audible speech signal, and familiar and easily understood language where the main factors considered to determine whether speech is intelligible are a) spectral components, b) the timing of acoustic events and c) the position of the voice source in relation to the listener (ASHA, 1995; Finitzo-Hieber, 1988; Crandell and Bess, 1986; Pekkarinen, 1988; McGlashan and Howard, 2001; Wanzer and McCroskey, 1998; Howard and Angus, 2001).

2.2. THE VOICE

2.2.1. Acoustic and perceptual characteristics of the voice

In voice research, voice is studied in terms of physiological factors (e.g., activity in respiratory, laryngeal or articulatory muscles), physical factors (e.g., expiratory force), acoustical factors (study of sound) and perceptual factors (how voice is perceived). According to Hirano (1975) voice is studied from parameters a) which regulate the vibratory pattern of the vocal folds (in terms of physiological and physical activity), b) which specify the vibratory pattern of the vocal folds (in terms of physical) and c) which specify the nature of the sound generated (in terms of acoustical and perceptual). Parameters which specify the nature of the sound generated can be summarized as in table 1. Some of these factors will be discussed in more detail in what follows.

Table 1. Factors which specify sound generated. Modified from Hirano, 1975. The factors on the left and the right describe the same phenomenon from different points of view (acoustical and perceptual)

Factors which specify sound generated

Acoustic	*Psycho-acoustic*
Amplitude (Intensity) Fundamental frequency Waveform. The acoustic spectrum Fluctuations : 1) large, slow changes 2) small, rapid, irregular	Loudness Pitch Quality Fluctuations: 1) Trembling 2) Hoarseness

2.2.2. Glottal vibrations

"The aerodynamic aspect of phonation is characterized by four factors: subglottal pressure, supraglottal pressure, glottal impedance and the volume velocity of the airflow at the glottis" (Hirano, 1981, p25). Before vocalisation can begin the vocal folds are adducted using adductor muscles and as Borden and Harris (1984, p82) state: "A necessary condition for voicing is that the air pressure below the folds must exceed the pressure above the folds". During the course of vocalisation the vocal folds are brought together by the so-called "Bernoulli force", causing the vocal folds to vibrate owing to differences in the air pressure above (supraglottal) and below (subglottal) them. Each sine wave in those vibrations has its own characteristics, as described by Leavitt (1978): "Three basic components of a simple periodic vibration are frequency, intensity and phase".

2.2.3. Intensity regulation

"The average or overall sound pressure level in decibels provides an indication of the strength of the vocal fold vibration. If a person speaks softly, the overall sound pressure level (SPL) will be low. Conversely if a person speaks loudly, the overall SPL will be high" (Colton and Casper, 1990, p22).
The intensity of the voice is measured acoustically as sound pressure level (SPL) by the formula:

$$\text{dB (SPL)} = 20 \log_{10} \left(\frac{P_0}{P_r}\right)$$

where P is the sound pressure of voice (in Pascals, Pa). P_0 refers to the pressure measured (the output), P_r refers to the pressure used for comparison or the standard reference pressure 20µPa (the lowest sound pressure detectable by the humans). Intensity is proportional to the pressure squared (Leavitt, 1978, p60).

2.2.3.1. Subglottic pressure

In the literature it is demonstrated that the loudness of phonation is mainly controlled by subglottic pressure (the expiratory effort that determines the flow rate) (e.g., Sundberg, 1987; Gauffin and Sundberg, 1989; Borden and Harris, 1984). In normal speech the subglottic pressure ranges from 5 -10 cm H_2O. See Hirano (1981, p38) for further review. A doubling of the subglottic pressure leads to 9 dB increase in the sound pressure level (Sundberg, 1987, p39). The louder the voice the more subglottic pressure is exerted, and the subglottic pressure tends to be highest for high pitched sounds (e.g., Isshiki, 1964). There is a six to sevenfold increase in subglottic pressure if the voice is raised from soft to loud phonation (for females from 0.33 to 2.02 kPa; for males from 0.33 to 2.29 kPa; 1 kPa = 10 cm of H_2O), resulting in higher SPL and higher F0 (Vilkman et al., 2002). The average variation range of subglottic pressure seems to remain stable throughout adulthood and does not differ by gender (Hiss et al., 2001). Subglottic pressure which is affected by resistance against the flow of air through the glottis is significant for the amplitude and also to some degree for the frequency of phonation. When subglottic pressure is raised an increased adduction may be required for continuing the vocal fold vibration. When we increase loudness of phonation we have a tendency to increase both vocal fold tension and adduction. An increase in phonation frequency does not necessarily cause an increase in subglottic pressure. Under such circumstances a manipulation in laryngeal muscles takes place (Sundberg, 1987, p16).

2.2.3.2. The negative peak amplitude of differentiated glottal flow

The amplitude characteristics of glottal flow can be determined by AC amplitude of glottic flow (f_{AC}) and negative peak amplitude of differential glottal flow (d_{peak}) (also called "maximum flow declination rate" by Holmberg et al., 1988). Holmberg and colleagues 1988) found, when shifting from normal to loud voice use, increased subglottic pressure, increased AC flow and an increased maximum airflow declination rate. An increase in d_{peak} values is associated with increased energy of the harmonics and intensity of voice (Gauffin and Sundberg 1989, Alku et al., 1999)

2.2.3.3. Resonance

As the subglottal pressure seems to be the main factor in controlling the intensity, the vocal tract as a resonator appears to play a definite role in providing for an increase in the SPL. The first 4 formants (formant = a resonance of the vocal tract) are considered the most relevant ones (Sundberg, 1987, p12). This is because these lowest formants naturally fall to the lowest and thus strongest overtones of the voice and consequently the acoustic energy of these lowest formants is greatest. The whole voice gets stronger. Additionally, the voice can become stronger if two or more resonances approach each other. If the frequency distance between two adjacent resonances is halved, both resonances gain 6 dB and the overtones between these resonances gain 12 dB (Sundberg, 1987, p95). When singing at high pitch sopranos learn to raise F1 (by opening the mouth wider) to the frequency of F0 and may gain even 30 dB in intensity (Sundberg, 1987, p126-127). Lip radiation also increases SPL for 6 more dB per octave (Howard and Angus, 2001, p31)

2.2.3.4. Role of F0

Raising F0 actively (e.g., by contraction of the crico-thyroid muscle) is an effective way of raising intensity. Seidner (1986) pointed out that speaking pitch may rise one octave from normal speech to shouting. With increased F0 there is less time for the vocal folds to make their movement and therefore the closing phase is faster, resulting in increased intensity as d_{peak} increases. Additionally, subglottic pressure raises F0 since it stretches the vocal folds laterally and thus makes them stiffer (Titze, 1984). Stiffer material, in turn, vibrates at a higher frequency.

2.2.4. Intensity and loudness

The term “loudness” is used for the psychological sensation of a sound i.e. how the human ear judges the intensity. Intensity and loudness are not perfectly correlated as the sensation of loudness increases more slowly than the actual increase in intensity (Borden and Harris, 1984, p40). Voice quality can affect loudness even without affecting intensity. According to Sundberg (1987) a rise of subglottal pressure from 7–14 cm H_2O raises the fundamental frequency about 28 Hz in moderately loud voices.

For example in a study by Lauri et al. (1997) the difference between soft and loud speech phonation was measured and results showed a rise from 62.9 dB to 98.7 dB for female voices. In a study by Vilkman et al. (2002), the rise was from 63.8 dB to 100 dB for male voices. According to this the difference between soft and loud speech phonation is approximately the same for both genders, roughly 30 dB. However, the variation between soft and loud voices can exceed 60 dB in singing (Åkerlund and Gramming, 1994; Titze, 1994). Coleman et al. (1977), using phonetogram procedure, measured the highest intensity for a female voice at 122 dB and for a male voice at 126 dB. The minimum SPL was measured at 48 dB for a female and at 51 dB for a male. The distance from the microphone to the speaker's lips was six inches.

Vocal intensity has been assigned to 3 levels by Buekers et al. (1995) where the microphone distance was 30 cm from the mouth and Vilkman et al. (2002), where the microphone distance was 40 cm from the mouth:
Soft speech < 50 – 70 dB
Loud speech 70 – 90 dB
Screaming 90 dB.

Table 2 shows the vocal effort of a speaker measured at two different distances according to international standard assessment. Webster (1979) pointed out that speech sounds vary widely in SPL and F0 during speaking. Under most conditions (up to 78 dB(A)) when a person is instructed to speak in a "normal" tone of a voice the A-weighted sound level for most talkers is usually 50-65 dB(A) at a distance of 1 m from the talker. As the ear is not equally sensitive to all frequencies, a frequency-weighting method, called A-weighting, is used to imitate human hearing. Lower frequencies (below 1000 Hz) are damped with respect to the middle (between 1 and 5 kHz) and high frequencies (over 5 kHz) "A-weighting has a frequency dependence that corresponds to that of the equal-loudness contours at low levels" (Zwicker and Fastl, 1999, p205).

Table 2. The vocal effort of the speaker according to ISO 9921-1, 1996

Vocal effort	A-weighted sound level dB(A) at 1 meter	A-weighted sound level dB(A) at 0.3 meter
Maximum	90	100
Shout	84	94
Very loud	78	88
Loud	72	82
Raised	66	76
Normal	60	70
Relaxed	54	64

Circumstantial factors such as background noise, acoustics and distance can affect the intensity of the voice. For example, a speaker has a tendency to increase SPL when speaking against a background noise (Lombard's effect; van Heusden E, Plomp R, Pols LCV: Effect of ambient noise on the vocal output and the preferred listening level of conversational speech. Appl Acoust 1979;12:31-43.). Room acoustics affect the dB level that is obtained e.g., to phonate at 80 dB measured at a distance of 1 meter is much easier in an office with an average reverberation time than in a well damped studio. There is also a tendency for a speaker to raise the SPL in large rooms or when speaking to a large audience. Therefore in work places where speech communication is essential it is recommended that the A-weighted sound level for background noise does not exceed 63 dB(A) for satisfactory communication at the distance of 2 meters (Webster, 1979).

2.2.5. Fundamental frequency and pitch

F0 is assumed to be controlled mainly by a) contraction in cricothyroid muscles (CT), b) contraction in thyroarytenoid (TA) muscles and c) by changes in lung pressure (Titze, 1994). Thus, phonation frequency is mainly determined by the length, mass and tension of the vocal folds and changes in subglottal pressure. Furthermore, Vilkman and Karma (1989) showed that vertical position of the hyoid bone causes vertical stretch to the laryngeal tissues and raises F0. Additionally, different vowels seem to cause small but significant differences in F0 values in speech utterances i.e. high vowels tend to have a higher F0 and low vowels have a lower F0 (Honda and Fujimura, 1991). This is assumed to be partly caused by the tongue's effect on laryngeal position and reflexive CT activation in vowel articulation (Honda, 1983).

According to the literature (See for a further review Krook, 1988) the mean F0 for female voices at conversational loudness can vary between 164 and 255 Hz and for male voices between 100 and 146 Hz. The individual "habitual pitch" (the voice used in neutral speech during the day without any vocal loading) varies relatively little, as measured from day to day, and even from year to year (Coleman, 1993). If the voice loudness is raised from soft phonation to loud phonation the F0 variation can be doubled or more. For example in a study by Vilkman et al. (2002) the mean rise was 149 Hz for female voices (from 153 Hz to 302 Hz or about 12 semitones) and 150.9 Hz for male voices (from 91.1 Hz to 242 Hz, or about 19 semitones) when shifting from soft to loud voices.

A number of researchers have shown that there may be considerable differences between individuals, both male and female, in the mean F0 of their voices, and there can also be differences in F0 between samples of speech spoken by the same individual. These differences in mean F0 have been attributed to various causes (e.g., cultural and linguistic factors.) For example, the mean F0 in Swedish female voices has been reported to be lower than the mean F0 in English, French and German voices (Krook, 1988). Emotional factors also affect F0 in speech. For example, emotions such as anger and enthusiasm are typically related to higher F0 (and SPL; see, e.g., Laukkanen et al., 1996). Circadian rhythms (i.e. the changes in body temperature and heartbeat during 24 hours) significantly affect F0. According to Bouhuys et al. (1990) in 14 depressed patients F0 was shown to follow the circadian pattern: mean F0 measured as semitones tended to rise from 1 am to 10 am by 0.6 semitones, stay steady between 10 am to 1 pm, and then decrease by about 0.2 semitones till about 7 pm, to rise again by 0.1 semitones till 10 pm. Other factors may include variations in the ages of the subjects (Luchsinger and Arnold, 1965; Honjo and Isshiki, 1980) different sizes of the larynx (Titze, 1994) and state of health. Differences in the range of testing materials used may also affect measurements e.g., whether the subjects were required to read a text, or to speak spontaneously, or to sustain a single vowel. See for further review Rantala et al. (1997).

Like intensity and loudness, fundamental frequency and perceived pitch are not exactly equivalent. Physiologically, the fundamental frequency (F0) is the number of vocal fold vibrations per second (f); acoustically, it is the inverse of period (T) length or $f = 1/\ T$

(Leavitt 1978, p49). Perception of pitch, on the other hand, is subjective. Voice quality, signal duration and also to some extent sound intensity affect our judgement of pitch (Zwicker and Fastl, 1999). Timbre affects pitch perception so that sound with a brighter timbre sounds higher in pitch. In terms of acoustic measurement F0 is measured as Hz, but for perceptual judgement variations in F0 are measured as semitones by the formula 39.86 x log (F0 / 16.35) (Frøkjær Jensen and Prytz, 1976).

Environmental circumstances can affect the pitch; it is automatically raised against noise, in larger rooms and/or to larger audience (Van Heusden,1979). The degree of indulgence in damaging activities may also be significant. The pitch becomes lower when the subjects are heavy smokers (Stoicheff, 1976; Comins, 1990; Murphy and Philip, 1987).

In their investigations on the speaking fundamental frequency of storytellers, made over a number of years, Coleman and Markham (1991) assumed that a variation which amounts to ± 3 semitones in repeated measures of average speaking fundamental frequency may be considered a realistic value for variation of F0 range in speech.

2.2.6. Phonation time (F0 time)

Phonation time is the time during which the vocal folds are vibrating. It is possible to estimate the total number of vocal fold vibrations and thereby the work loading on the vocal folds. By excluding all pauses and voiceless segments of speech the number of cycles per second is multiplied by the vibration time of the vocal folds and the result is divided by one thousand (called "index of voice loading" by Rantala and Vilkman, 1999):

(F0 x F0 time) / 1000

F0 time is given in seconds. Rantala and Vilkman (1999) found that the index correlated positively with the number of the subjects' voice complaints i.e. the more voice complaints the subjects had, the higher was the value of the index of voice loading.

2.2.7. Voice quality

2.2.7.1. Laryngeal level

"Personal voice characteristics are determined by the formant frequencies and the voice source" (Gauffin and Sundberg, 1989). The sound that comes from vocal fold vibrations is called "voice source" and is mainly controlled by means of the respiratory and laryngeal muscles. Voice source is characterized acoustically by fundamental frequency, amplitude and spectrum, or perceptually by pitch, loudness and timbral characteristics (Sundberg, 1987, p51). The opening and closing of the glottis result in a sequence of quasi-periodic air pulses sent into the vocal tract which may be regarded as a resonator. As the shape of it is easily changed by movements of the articulators it affects the frequencies of a voiced sound during speech. Those resonance frequencies created in the vocal tract are referred to as “formants” (Titze, 1994, p143). To estimate the original glottal flow waveform or the voice source inverse filtering is used. By inverse filtering, the formants can be cancelled making it possible to study the vocal fold vibrations (Titse, 1994, p333; Sundberg, 1987, p77).

Measurement of the voice source may include measurement of AC amplitude and several time-based parameters (fig. 1).

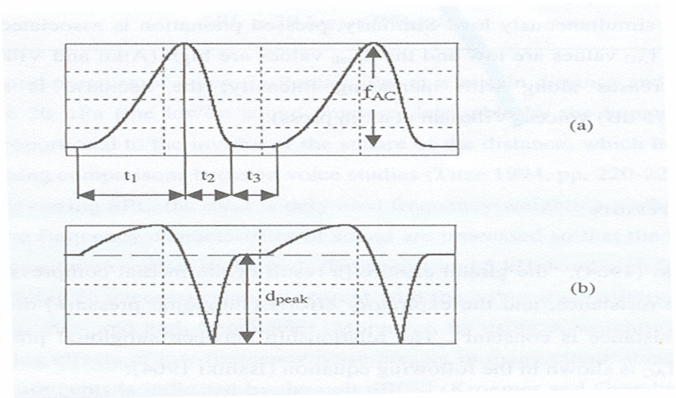

Figure 1: Two periods of a glottal flow (top panel). f_{AC} =amplitude of the flow. Open quotient (OQ = t1 + t2 / T). Speed quotient (SQ = t1 / t2). Closing quotient (CQ = t2 / T) where T denotes the length of the fundamental period (T = t1+t2+t3). The bottom panel shows the first derivative of the glottal flow. d_{peak} = negative peak amplitude of the differentiated glottal flow. Figure from Alku et al. (1998).

There are different modes of phonation. In breathy or hypofunctional voice production the adduction is not sufficient in relation to subglottic pressure. Therefore the glottis does not close completely and the voice source amplitude is relatively large (higher peak flow) and the relative closed time of the glottis is short. There is a longer delay between peak flow and peak differentiated flow (relatively slow closing of the glottis). SPL is typically low. In contrast, phonation becomes “pressed” (i.e. strained) or hyperfunctional as the adduction force is exaggerated i.e the adduction is too strong in relation to subglottic pressure. Then the voice source amplitude is small (low peak flow), the closed time is longer and there is shorter delay between peak flow and peak differentiated flow (relatively fast closing of the glottis) (Gauffin and Sundberg, 1989; Sundberg et al., 1993).

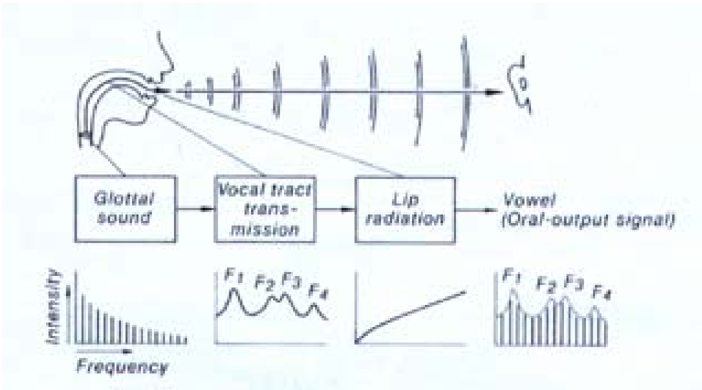

Fig 2: Transfer function of the vocal tract and the spectrum (Hirano,1981, p67).

A description of a certain aspect of the voice source is its composition of harmonic partials, the frequencies of which are f1 =1 x F0, f2 = 2 x F0, f3 = 3 x F0, f4 = 4 x F0 i.e. the frequencies which form a harmonic series. Harmonic partials can be studied with spectrum analysis. Borden and Harris (1984, p279) defined amplitude spectrum as "A graphic representation of a vibratory event in which the ordinate (the vertical axis) represents the amplitude of the signal while the abscissa (the horizontal axis) represents the component frequencies".

The lowest tone in the spectrum is called "fundamental" and all other tones "overtones". The level of the fundamental depends on the amplitude of vocal fold vibration. This, in turn, correlates with the amplitude of AC flow (the pulsating airflow) in voice source. The greater the amplitude, the stronger the fundamental frequency. The overtone content of the voice source depends on how fast the glottis cuts off the transglottal airflow in the closing phase; the faster the closure, the stronger the overtones (Gauffin and Sundberg, 1989). When loudness of phonation is increased, the amplitude of the spectral overtones increases considerably more than the amplitude of the fundamental, and higher overtones tend to increase more than lower overtones. An overtone is often the strongest partial in loud phonation rather than the fundamental (Fant, 1960). On the other hand, lower source spectrum partials are much more prominent in quiet phonation than in loud phonation." (Sundberg, 1987, p72)."

The smoother and more sinusoidal the waveform is, the softer the higher partials are, and conversely, the more abrupt the changes are in the waveform, the stronger the high partials of the spectrum will be. This is in line with the results of Hammarberg (1992), according to which the level of the fundamental frequency is low relative to the first formant in hyperfunctional and strained voices, while the opposite is true for hypofunctional and breathy voices. Male voices have a weaker fundamental in source spectrum than female voices which are characterised by a strong source spectrum fundamental (Sundberg, 1987, p67).

Voice quality refers to perceived impression of voice, and the main acoustic correlate of it is sound energy distribution along the frequency range. Voice quality (at the laryngeal level) is partly due to the way in which the vocal folds vibrate, partly to how closely the vocal folds are aligned (e.g., influenced by the presence of irregularities along the edges of the folds (Borden and Harris, 1984, p87). “Timbral characteristics depend on the properties of the vocal fold vibrations which in turn depend on both the laryngeal musculature and the subglottal pressure” (Sundberg, 1987, p44).

Sound energy distribution is studied by measuring acoustic energy in selected frequency ranges. This can be achieved by measuring a factor called Long-term-average-spectrum (LTAS). “The long-term-average-spectrum provides information on the spectral distribution of the speech signal over a period of time” (Löfqvist and Manderson, 1987). The measure of SPL difference between the ranges 0 – 1 kHz and 1 - 10 kHz provides a measure of the overall tilt of the spectrum. According to Löfqvist (1986) a high value of (SPL 0-1 kHz) - (SPL 1-10 kHz) indicates that the fundamental and the lower harmonics dominate. The spectrum thus falls off rapidly (soft or hypofunctional voice). Conversely, a low value shows that the source spectrum has a lower spectral tilt (strong or hyperfunctional voice) (Childers and Lee 1991, Gauffin and Sundberg, 1989). Inverse results will be obtained if the level difference is calculated either as energy in 1-10 kHz / energy in 0-1 kHz or as (SPL 1-10 kHz) - (SPL 0-1 kHz) (alpha ratio, Frøkjær-Jensen and Prytz, 1973 and 1976).

2.2.7.2. Voice and speech quality at the supralaryngeal level

At supralaryngeal level vocal tract resonances and formants modify sound energy distribution and thus greatly affect voice quality. On the basis of the *source filter* theory (Fant, 1960) the sound source is the time-varying glottal airflow and the vocal tract is the filter. During speech production, movements of the articulators cause changes in the shape of the vocal tract. The filter (the vocal tract) of the source filter model (fig. 2) is therefore time-varying during speech production. This has the effect of changing the frequencies of the formants in their response to these alterations - the so-called formant transitions. The speed of formant transitions varies with different speech sounds. In English this time varies from 10 msec for plosives (e.g., [b/p/d/t/g/k]) to 250 msec for diphthongs. The syllable length in speech is approximately 250 msec on average (Howard and Angus, 2001). According to Sundberg (1987), the movement in any of the articulators generally affects the frequencies of all formants especially the lower formant frequencies. Indeed, articulation determines the frequencies of the formants, especially for the two lowest ones which also happen to be the most important formants for linguistic information. Each vowel sound is associated with a specific articulatory profile producing a specific area function that in turn gives a specific combination of formant frequencies. The higher the formant the more its frequency depends on non-articulatory factors such as vocal tract length. Difference in pharyngeal length is significant for the timbral classification of the voice. Every vowel can be articulated in various ways with various jaw openings, various positionings and shapes of the tongue, and various larynx positions. This is reflected in varying combinations of formants.

First formant. The lowest formant up to 1 kHz. Always rises as the jaw opening is increased (Sundberg, 1987, p 99).
Second formant. Between 1 and 2 kHz. Changes considerably as the tongue shape is shifted (Sundberg, 1987, p99).
The first and second formants are the main determinants of vowel quality (Fant, 1960, p46).
Third formant. Between 2 and 3 kHz. This formant is sensitive to the position of the tongue tip or to the size of the cavity behind the front teeth. For speech perception this formant is more important for front vowels than for back vowels (Fant, 1960, p121). The three first formants for, e.g., the vowel [i:] can be for a speaker F1 300 Hz, F2 2500 Hz and F3 3000 Hz, (Borden and Harris, 1984, p102).
Fourth formant. Between 3 and 4 kHz. The fourth formant is highly relevant for the voice timbre or "to the personal component in the sound of the voice" (Sundberg, 1987, p101). Lowering of the larynx causes marked lowering of the third and fourth formant frequencies (Sundberg, 1987). These formants in particular make a significant contribution to the phonetic quality of the front vowels. As a rule of thumb, the lower the formant frequencies the darker the timbre, and the higher the formant frequencies the brighter the timbre. A bright voice with more sound energy in the 2-5 kHz region sounds louder and projects better than a darker voice. Formant frequencies are also used to carry information of e.g., emotions. The most straightforward example of this is the fact that smiling can be heard in the voice through raised formant frequencies compared to those used in neutral speech (Laukkanen et al., 1997).

2.2.8. Factors affecting the voice

2.2.8.1. Auditory feedback mechanism

Study results have identified the role of auditory feedback in monitoring and controlling speech and voice production. Auditory feedback is a fundamental necessity when singing if the singers are to hold pitch (Sundberg, 1987, p61). People seem to have a tendency to increase pitch and loudness when feedback is damped (Lane and Tranel, 1971; Chang – Yit et al., 1975). Auditory feedback is important in the control of phonatory quality. The monotonous, uncontrolled and often high pitched voices of the deaf illustrate this. A summary of studies on auditory feedback can be seen in table 3.

Table 3. A summary of studies on auditory feedback.

Author	Subjects Fem.	Mal.	Method	Results
Chang – Yit et al. (1975)	6	3	Auditory feedback modulated gradually during a session.	Decreased vocal intensity when the subjects heard their own voices amplified both in noise and no-noise condition.
Sundberg et al. (1987)	9		Effects of speaking in noise and of speaking with differently filtered auditory feedback.	Reduced vocal intensity when high-frequency components of auditory feedback were increased.
Laukkanen (1990)	41		Reading loud with (1) own voice in headphones. (2) filtering of the voice. (3) masking noise in the headphones. (4) artificial frequency changing.	(1) and (2) decreased voice loudness; (3) increased voice loudness; (4) pitch changes.
Laukkanen (1994)	24	4	Reading aloud with and without hearing own voices. Pitch manipulation of the auditory feedback.	In most cases reading pitch increased during pitch-changed auditory feedback.

2.2.8.2. Vocal loading

Prolonged voice use is called "vocal loading". Probably the most common consequence of vocal loading is a rise of the average fundamental frequency (F0) and sound pressure level (SPL) (Kitzing, 1979; Gelfer et al., 1991; Rantala and Vilkman, 1999; Rantala et al., 1998; Stemple, 1995; Lauri et al., 1997; Buekers et al., 1995; Vilkman et al., 1999). Additionally, spectral changes take place, e.g., after vocal loading the alpha ratio has been found to be higher for females, suggesting a change towards a more hyperfunctional voice, and lower for males, suggesting a change towards a more hypofunctional voice (Novak et al., 1991). While many researchers have found an increase in F0 and SPL, others have found no or little change in F0 after vocal loading, e.g., Garrett and Healey in female voices (1987) and Stone and Rainey in both female and male voices (1991). Differences in the results may be related to differences in the loading test (length of the test, SPL required etc.) or in the subjects. Field studies on vocal loading (Ohlson, 1988; Rantala et al., 1994; Rantala et al., 1998) have shown higher values of F0 than laboratory studies (e.g., Neils and Yairi, 1987). According to Rantala et al. (1998), this difference in average F0 could amount to 69Hz for a subject. The values obtained in the laboratory were within the limits of mean F0 reported in literature (see Krook (1988) for further review). However, the F0 values obtained in the field results exceeded those limits. Reasons for higher F0 in field studies are most likely related to higher SPL when one is speaking to a larger audience in a larger room, and to communicative factors.

2.2.8.2.1. Warm up

The initial stages of vocal loading are known as "vocal warm-up". Vocal warm-up occurs approximately during the first half hour of speech, when vocal loading does not exceed the vocal capacity of the subject (Sherman and Jensen, 1962). It has been hypothesized that during vocal warm-up blood circulation in the vocal folds is improved in order to retain good function and viscosity (Sundberg, 1984, p193). Titze (1984) hypothesizes that slight edema due to vocal loading may cause lowering of viscosity. However, increased edema due to prolonged loading may cause the vocal folds to move less regularly resulting in impaired voice quality with roughness. A warm-up period is considered to be beneficial for the voice. Subjects feel that the voice sounds stronger and is better adjusted and they also feel more alert and energized (Scherer et al., 1987; Sherman and Jensen, 1962). For review of postulated effects and mechanism of vocal warm up see Vintturi (2001), p31. Laukkanen et al. (1998) found a decrease in glottal resistance after a minute of phonation on certain vocal exercises. This may either indicate a warm-up effect or a change in phonatory setting due to the exercises.

2.2.8.2.2. Vocal fatigue

If vocal loading is sustained over a long period or if it is excessively strong it may lead to vocal fatigue. Sapir et al. (1993) describe vocal fatigue as "voice tires easily when talking or singing" and it is described by Gotaas and Starr (1993) as "a problem that begins to occur as the speaking day progresses, is most evident at the end of the day, and usually disappears by the following morning".

Vocal fatigue results in negative changes in vocal quality and is identified by a variety of symptoms. According to Scherer et al. (1987) vocal fatigue includes "vocal quality changes, vocal limitations, deterioration of vocal control, discomfort in various parts of the body, and changes in laryngeal tissues". However, it has been found (Laukkanen et al., 2001) that perceived vocal fatigue does not correlate well with subjects' sensations of fatigue, which are experienced as various symptoms in the throat. According to Colton and Casper (1990, p37) signs that may be associated with the symptoms of vocal fatigue can be defined as a) *perceptual* (i.e., voice becomes monopitched, tensed, breathy or hoarse), b) *acoustic* (phonational range is restricted and variability of fundamental frequency is reduced), c) *laryngoscopi*c (variations of vocal fold approximation, tissue changes, e.g., nodules, muscle tension or normal appearing larynx) or d) *physiological* (increased airflow or inadequate closed time). Finally, muscle imbalance can be noticed.

The symptoms of vocal fatigue may be caused by:
a) *Tiredness* of either the laryngeal or the respiratory muscles (Titze, 1994, p323; Brodnitz, 1971). Vocal fatigue is thus attributed to fatigue in the laryngeal muscles

caused by strenuous use of the voice, resulting in loss of the lowest pitches and a rise of the comfortable pitch (Titze, 1994). Forchammer (1974) describes how, like any other muscles in the body, the laryngeal muscles can get tired. But this fatigue is not organically detectable and can be detected only when voice production breaks down.
b) *Hyperfunctional voice use*. It is also hypothesised that vocal fatigue may be caused by lack of balance between the respiratory support and laryngeal muscle effort (Sander and Ripich, 1983), excessive use of high pitch (Stone and Sharff, 1973), excessive use of high SPL (Zagoruiko and Tambovtsev, 1982) or decreased airflow (Kostyk and Rochet, 1998).
c) *Phonation time.* The results of Rantala and Vilkman (1999) suggested that increased F0 time is a bigger risk factor for vocal fatigue than increased F0. Phonation time for pre-school and elementary school teachers has been found to be three times longer than for office workers: the average of the phonation time for 8 hours was 95.2$\pm$ 13.6 min for the preschool teachers, 103.6$\pm$28.0 min for the elementary school teachers and 33.0$\pm$13.6 min for the office workers (Masuda et al., 1993).
d) *Loss of blood circulation* through the tissue because of internal pressure of the muscle tissue (Titze, 1994, p323).
e) *Straining* of laryngeal ligaments, joints and membranes (Titze, 1994, p323).
f) *Locked cricothyroid visor*. Harris and Lieberman (1993) stated that the cricothyroid visor could not relax after extensive voice use and remained tightly closed and even if the patient was not actually voicing the muscular effort in the larynx stayed maximal all day.
g) *Changes in tissue viscosity* of the vocal folds (Verdolini-Marston et al., 1990; Titze 1994, p323; Titze, 1989). When the tissue viscosity of the vocal folds increases it makes it harder for the vocal folds to maintain vibrations because of increased internal friction. This may result from dehydration as mechanical energy is dissipated into heat when tissue vibrates. More power is dissipated at high notes than low notes so voice use at high notes poses special problems with vocal fatigue (Titze, 1994 p 325) Verdolini-Marston et al (1990) demonstrated how the phonation threshold lowered with higher level of hydration.
f) *Lesions* in vocal fold tissue (Scherer et al., 1987; Sonninen, 1974; Gray et al., 1987). Strenuous phonation increases the risk for vocal fatigue, which in turn can lead to pathological changes in the vocal fold tissue (Scherer et al., 1987; Mann et al., 1999*).* Gray (1991) showed that the basement membrane zone (BMZ) in the superficial layer of the vocal folds can be at risk of damage due to vibratory stress under vocal load.

The consequence of damage is often a dysphonic voice. In addition to causing varying degrees of inconvenience to the voice patient him/herself, dysphonia may have a negative impact on message transfer in communication (Greene and Mathieson, 1991). Various investigations have shown how dysphonic voices lack intensity, range and normal frequency distribution (Gramming, 1988; Kitzing and Åkerlund, 1991; Hirano et al., 1991). Changed vibratory patterns because of increased stiffness, lesions or nodules in the vocal folds, lack of vocal fold closure or over-adduction of the vocal folds change the voice quality, and the voice becomes hoarse, husky, raspy, breathy or harsh (Martin, l987; Siegert, 1965). Additionally, F0 and SPL often become lower than normal in diseased voices (Hirano et al., 1991; Gramming, 1991).

However, it appears that there are individual differences in levels of voice endurance, so not all voice users experience voice problems. This is in part due to physiological differences between individuals or as Colton and Casper (1990, p79) describe, "Each individual larynx has a physiological limit that varies not only from person to person but also intra-individually as influenced by numerous factors". Fawcus (1991) points out that some people tolerate vocal exertion better than others. She established that some people became temporarily hoarse after using the voice against a high intensity background noise, while other people did not. In a vocal loading test (Vilkman et al., 1999) females were able to produce their loudest voice in the last loading sample of a day, which the researchers suggested could not point to any weakness in laryngeal or respiratory muscles. The results may though indicate that the loading was not sufficient to cause fatigue. It is also known that genetic factors influence voice quality but research into this is still scant. Sataloff (1993) asks an interesting question - "To what degree do density, size, twisting architecture (sic) vary from person to person, and what effect do the details of the connective tissues framework have on function?" (p26). He asserts that if responses were available to such questions it would be possible to identify high risk groups for vocal fatigue and assist them in preventative measures.

Well-trained voices have greater SPL and greater F0 range in speech than untrained speakers (Awan, 1993) and show less manifestation of vocal fatigue (Novak et al., 1991; Gelfer et al., 1991). Scherer et al. (l987) demonstrated how a trained voice endured longer than an untrained voice. Currently, it looks as if it is possible to increase endurance by vocal training, possibly due to adaptation of the vocal fold tissue. However, there is also a possibility that people with better vocal fold tissue are more interested in training their voices and thus all the differences between trained and untrained voices are not necessarily attributable to the effects of training.

2.2.9. Risk factors for vocal fatigue

If we look at table 4 showing some risk factors associated with vocal loading in professional voice users, it can be seen that teaching leaves the teacher open to many work-related risk factors. Some of the risk factors will be addressed in more details in chapters 2.2.9. and 2.3.

Table 4: Some voice-dependent risk factors in voice professions. Modified from Vilkman (2000).

Work-related	Individual factors
Vocal loading (speech and song) Stress Poor working posture Inadequate treatment of early signs Air quality, dryness, dust Poor room-acoustics Background noise Long distance between speaker and listener	Weak voice Poor technique Poor voice habits Personality Respiratory diseases Smoking

2.2.9.1. Intensity of speech

As to risk factors, the main hazard can be considered to be prolonged use of the voice itself (Vilkman, 2001, p129), which is related to the type of phonation used and the amount of vocalisation required during a working day. Speaking to a large group or over a large distance or against background noise requires higher SPL. According to Webster (1979), increase in SPL of speech is as much as 6 dB for every 10 dB increase in noise level if it is important for each of the talker's words to be understood. Van Summers et al. (1988) have presented results showing that F0, SPL and duration of speech sounds increase in noise; furthermore, spectral tilt decreases. Raised F0 is both a consequence of increased SPL and a way to raise SPL further. Increased adduction is related to raised SPL - and also to the aim of improving message transfer in noisy conditions. By increasing adduction the overtones get stronger, which improves the realisation of formants.

According to Jing and Titze (1994) the force with which the vocal folds collide increases as a function of F0, SPL and adduction. In hyperfunctional voices adduction is high. This means higher mechanic loading on the vocal fold tissue. Such strenuous phonation increases the risk for vocal fatigue, which in turn can lead to pathological changes in the vocal fold tissue (Scherer et al., 1987; Mann et al., 1999*)*. On the other hand, raising the SPL does not necessarily lead to vocal fatigue according to Neils and Yairi (1987) and Stone and Sharf (1973).

2.2.9.2. Subject and grade taught

Certain groups of teachers seem to be at greater risk of developing voice problems than others. Buekers (1995), Smith at al., (1998 (b)) and Verdolini-Marston (2001) have reported that teachers of physical education and sport may be at greater risk of developing vocal symptoms than other teachers. Because of the nature of their work and their working environment these teachers face great vocal demands as they often have to use their voices in large, echoing sports halls, and outdoors where there is no acoustic feedback. Additionally, teachers of physical education exert a greater vocal effort than other teachers because of background noise during games or because they are required to speak while doing some gymnastic activity. According to Buekers et al.(1995), sports instructors used SPL levels of 72-78 dB during approximately one third of their phonation time. Vocal symptoms have been found to be common among female army instructors (Sapir et al., 1992) and aerobic instructors (Heidel and Torgerson, 1993) as well.

Other researchers have identified music teachers as particularly prone to develop vocal symptoms (Fritzell, 1996), probably because of extended voice use at higher pitch and higher intensity than in speaking. Still others claim that preschool teachers may be under the greatest risk of developing vocal symptoms (Fritzell, 1996; Unger and Bastian, 1981; Siegert, 1965). It is well known that preschool teachers have to work in circumstances where the background noise from children is particularly great. Sala et al. (2001) found in a study on the prevalence of voice disorders among preschool teachers and nurses that approximately 50% of the teachers had voice disorders, compared to 27% among the nurses.

2.2.9.3. Gender

In most western countries women form the majority of the teaching profession. This could partly explain why so many teachers complain of voice problems, as according to research results females are more likely to report voice problems. Smith et al. (1998 (a)) pointed out that 38% of 280 female teachers reported voice problems compared with 26% of 274 male teachers. Fritzell (1996) reported that 76% of teachers seeking medical help because of voice problems were females. Russel et al. (1998) stated that females seem to be twice as likely to suffer from voice problems as males.

The reason may not lie in any gender effects on personality (e.g., women more willing to seek help) but in gender differences in the structure of the vocal organ. There are good reasons to suggest that female vocal folds are more prone to develop vocal symptoms than male vocal folds (Bridger and Epstein, 1983; Russel et al., 1998; Herrington-Hall et al., 1988; Fritzell, 1996; Lauri et al., 1997; Goldman et al., 1996; Alku and Vilkman, 1996). Because of the smaller larynx, the fundamental frequency in female voices is considerably higher than in male voices i.e. the vibrations of the vocal folds are more rapid. Rantala et al. (1994) found that teachers' vocal cords vibrated during 15 - 40% of the teaching time. Vilkman (2000) calculated that a female elementary school teacher used 1,000,000 vibrations per day, based on the assumption that phonation time accounted for 30% of the teaching time (5 x 45 minutes per diem). Conversely, a male speaker would use only half the number of vibrations of the vocal cords due to lower F0 (Vilkman, 2000).

Approximately two thirds of patients with nodules are females (Herrington–Hall, 1988). The reasons are assumed to be rooted in gender differences in the vocal tissue, as well as in laryngeal structure. There is a greater percentage of collagenous fibres in the male vocal folds than in the female (Hirano, 1983), which could make the male vocal folds more enduring. Female vocal tissue may be slightly stiffer than male vocal tissue (Titze, 1989). However, according to Titze (1989): “there is no great difference between males and females in the type of tissue that is in vibration….. thus it is conceivable that hormonal factors and edema would have a significant effect on vocal tissue viscoelasticity”. It has been found that the vocal fold tissue contains hormone receptors and that these receptors vary according to age and gender of the subjects (Newman et al., 2000). Furthermore, according to Dejonckere (2001) the average number of glands and the amounts of glandular tissue are higher in males than in females; the glands and goblet cells help to lubricate the surface of the larynx. In Vintturi et al’s study (2001) females reading aloud in low humidity (25±5%) reported more subjective symptoms than males. Females may therefore be more adversely affected by low air humidity than males.

Additionally, female voices tend to become hyperfunctional more often than male voices, resulting in an increased SQ (speed quotient) and decreased ClQ (closing quotient) values as a response to vocal loading (Lauri et al., 1997). This has been considered as a risk factor because of increased collision force (Titze, 1989; Jiang and Titze, 1994).

2.2.9.4. Smoking, allergy and respiratory infections

Edema is considered to be a likely effect attributable to smoking, especially on the vibrating edge of the vocal folds. With continued smoking the mass of the vocal folds increases, which results in changes in the vibratory pattern of the vocal folds. It has been documented that smokers have lower fundamental frequencies than non smokers (Stoicheff, 1976; Comins,1990; Murphy, 1987).

Allergic reactions or respiratory infections in the upper respiratory tract can produce hoarseness or even complete loss of voice (e.g., Boone, 1991). The loose and pliable superficial layer of the vocal folds vibrates most markedly during phonation. It becomes stiffened by laryngitis (inflammation of the vocal folds and larynx). Chronic laryngitis resulting from e.g., long-term vocal abuse may lead to persistent inflammation eventual leading to thickening of the vocal folds. Impairment of the voice and vocal fold tissue is prone to impair message transfer. This leads to a need to raise effort. Unfortunately, impaired vocal fold tissue is also probably more vulnerable to fatigue and tissue lesions (Colton and Casper, 1990 p99). Gotaas and Starr (1993) found that teachers with allergic conditions suffered more from vocal fatigue than unaffected colleagues.

2.2.9.5. Hearing loss

Auditory feedback mechanism is essential for monitoring and controlling speech. It has been shown that voice intensity increases when masking has been employed (Lane and Tranel, 1971; Chang – Yit et al., 1975). Speakers who are partly deaf have less control over their voices, which may lead to deviations in pitch and timbre. Hearing problems typically result in the use of higher intensity F0 and increased adduction. This means more loading to the vocal folds. Conversely, Gotaas and Starr (1993) pointed out that teachers who suffered from vocal fatigue had more hearing loss.

2.2.9.6. Stress

A commonly held opinion is that anxiety can cause voice problems (Forchammer, 1974; Aronson, 1985; Boone, 1991; Raven, 1993; Kitch and Oates, 1994; Freidl et al., 1993). Boone (1991) pointed out that stress can be physical or situational or a combination of both. It can be found under certain circumstances in all occupations although stress is more inherited in some occupations than others. He also listed the twenty most common symptoms of stress in the voice: *breathy voice, double voice, dry mouth and throat, harshness, high pitch, hoarseness, lifting up of larynx, loud voice, low pitch, monotone, no voice (aphonia), neck or throat pain, pitch breaks, shortness of breath, strained voice, throat clearing, tight voice, traumatic laryngitis, voice breaks* and *weak voice*. Kyriacou and Sutcliffe (1978) investigated stress amongst 257 teachers who worked in sixteen medium-sized, mixed comprehensive schools in England. It was found that 20% of the teachers considered the job very stressful or extremely stressful, and they complained about being exhausted and frustrated. This is much in line with the findings of Sapir et al. (1993) and Raven (1993), who found that psychological stress is common amongst teachers. In Kyriacou and Sutcliffe's (1978) investigations the levels and nature of stress seem to be first and foremost dependent upon the personality of the teacher. There appears to be no link between the biographical characteristics of the teachers (sex, qualification, age, length of teaching experience and position held in the school) and self-reported teacher stress, according to Kyriacou and Sutcliffes' results. On the other hand, a more thorough study of the ergonomic conditions under which the teacher worked might reveal that the job itself may also be a substantial source of stress.

2.2.9.7. Posture

Little attention has so far been given to possible effects of posture on loading-related vocal symptoms. Bodily stance at work is too often a matter in which workers have little choice, and for teachers there are difficulties arising from the fact that they spend much of their time standing and leaning over pupils' desks. It seems plausible to suggest that a certain balanced posture and head position would give the most ergonomic conditions for muscle function also related to voice production.

It is obvious that posture affects the type of breathing. Iwarsson and Sundberg (1998) found connections between high lung volume and a lower position of the larynx. Furthermore, they indicated that the vertical position of the larynx has an influence on the F0 of the voice. Sundberg et al. (1987) found that there is a connection between a lowered laryngeal position and flow phonation (p84): "In flow phonation the amplitude [of the AC flow] is high, the closed phase long, [subglottic] pressure moderate, sound level high, and glottal area wide". Flow phonation, in turn, has been regarded as optimal from the point of view of message transfer and also from voice hygiene. Vintturi et al. (2001) found that during vocal loading, male voices demonstrated a greater change towards more pressed phonation when the subjects were in a sitting position than was found in phonation if they were standing. Interestingly these changes were not found in females voices. The position of the head is also of importance for voice production. Sonninen (1968) found that holding the head of the subjects immobile while singing caused increased lengthening of the vocal chords due to the activity of sternothyroid, sternohyoid and thyrohyoid muscles and the muscles of the floor of the mouth attached to the hyoid bone. These findings show how the head position affects the contraction of certain muscles in the laryngeal region which also may have effects on voice production.

2.3. THE CLASSROOM: EFFECTS WHICH MAY HARM THE TEACHER'S VOICE AND DIMINISH TEACHING EFFICIENCY

2.3.1. Environmental effects in general

Martin (1994) found that 44% of 95 teachers blamed environmental factors for their voice problems. In Jonsdottir's (1997) study a correlation was found between teachers' complaints of having a dry throat, pitch breaks and a lump in the throat and finding internal air quality bad. Many teachers have to work in poor surroundings such as overheated and stuffy buildings, with fumes from various noxious substances, dusty classrooms, poor air-conditioning, low oxygen levels, poor humidity, and poor acoustics with too long or too short reverberation time. Any one of these factors can lead to vocal abnormality (Colton and Casper, 1990; Sataloff, 1994; Hemler et al., 1995; Vilkman, 1996; Verdolini – Marston et al., 1990; Pekkarinen, 1988; Sala et al., 2002).

2.3.2. Air humidity

Lubrication is an essential element if the vocal folds are to be flexible under phonation. Sihvo (1997) found that the dynamic range of the voice range profile (VRP) decreased in low (25%) and increased in high (65%) air humidity. This is in line with the results by Verdolini-Marston (1990) which showed that more subglottal pressure was needed for phonation in dry (30-35%) than wet (85 -100%) conditions. It appears that a high ambient air humidity is beneficial for voice production. Andrews (1995) stresses that dry vocal folds become more easily irritated than folds with sufficient lubrication, indicating that adequate humidity is required for effective vibration of the vocal folds. Currently, the Occupational Health and Safety Executive in Iceland (Vinnueftirlit Ríkisins, 1990) considers that a humidity level of 35% is beneficial in classrooms. Sundell (1994) pointed out that low humidity, poor ventilation and too high temperatures caused evaporation. The formation of dust particles can also lead to Sick Building Syndrome, which amongst other symptoms results in dryness of the mouth and throat. Because of the severe weather conditions in countries such as Iceland it is difficult to change the classroom air. The measurement taken by the Vinnueftirlit Ríkisins (Administration of Occupational Safety and Health in Iceland) pointed to the fact that the air in Icelandic classrooms can be so dry that it may be difficult to use the voice in them without giving risk for rise to vocal strain. Therefore there is a possibility that Icelandic teachers live and work in too dry air conditions, increasing the risk of voice disorders due to drying of the mucous membranes of the vocal apparatus.

2.3.3. Poor acoustics and classroom noise

The classroom must have good acoustics if the pupils are to hear clearly what the teacher is saying. In fact, poor acoustics and classroom noise are probably the factors most commonly identified as impairing the intelligibility of speech in classrooms (e.g., Berg, 1993; Crandell and Smaldino, 1995 (b); Crandell, Smaldino and Flexer, 1995). Also they are probably the most common external factors highlighted as having a damaging effect on teachers' voices (e.g., Markides, 1986; Pekkarinen and Viljanen, 1990; Vilkman, 1996). Self-reported questionnaire responses on poor acoustics and voice problems have shown that they are significantly associated (Jonsdottir,1997; Morton and Watson, 1998). Information from 1200 teachers indicates that noise affects teachers' performance, in that they state that there is a direct link between classroom noise and fatigue (Ko, 1979). In Hétu, Truchon – Gagnon and Bilodeau's (1990) findings, 54% of classroom teachers and 77% of physical education teachers stated that noise commonly caused communication problems in their respective work environments, in contrast to 9% of office workers.

There are four principal factors which are considered to affect classroom acoustics and, thus, the teachers' vocal load. They also affect the student's ability to hear the teacher's instructions and explanations (e.g., Crandell and Smaldino, 1995 (a)):

Background noise

The signal to noise ratio

Reverberation time.

Teacher-student distance

These factors will be discussed in what follows.

2.3.3.1. Background noise in classrooms

It is recommended that the A-weighted sound level in work spaces where speech communication is essential should not exceed 62 dB(A) to permit satisfactory communication at a distance of 2 m (Webster, 1979). Classroom noise is derived from activities inside and outside the classroom. Berg (1993) stresses that for students' effective listening, noise levels should not exceed 40-50 dB(A) in occupied classrooms; in unoccupied classrooms the noise level should be set at below 35 - 40 dB(A). This assertion is confirmed by the findings of the American Speech-Language-Hearing Association (ASHA) which recommends that ambient noise level for optimum listening conditions in classrooms should not exceed 30-35 dB in unoccupied classrooms (1995). McCroskey and Devens (1975) found that only one of nine elementary school classrooms met these acoustical recommendations and in Crandell and Smaldino's (1994) findings none of 32 classrooms met recommended criteria. Smaldino and Crandell (1995 (b)) stated that noise levels in classrooms are in general 10-15 dB higher than recommended standards. Some examples show that conditions may be much worse than this. Sanders (1965) found that the noise level in one kindergarten was above 65 dB for 71% of the time and above 70dB for 25% of the time.

Moodley (1989) studied noise levels in 40 English schools over a period of several months. According to his results noise levels in occupied classrooms were unacceptably high (table 5):

Table 5. Average noise level (dB (A)) in classrooms at three different education levels (Moodley, 1989).

	Mean dB(A)	**Range dB(A)**
Nursery schools/classes:		
Empty classrooms	42.5	38.4 – 48.5
Class at work	75.0	65.0 – 85.0
Primary schools/classes:		
Empty classrooms	46.6	35.0 – 64.2
Class at work	65.3	47.5 – 81.3
Secondary schools/classes:		
Empty classrooms	45.3	35.0 – 62.7
Class at work	64.5	52.4 - 75.2

The results tally with the findings of various other researchers who have reported 55 - 77 dB(A) average noise levels in occupied classrooms (Marcides, 1986; Airey, 1998; Berg, 1993; Sanders, 1965; Berg, 1993). Additionally, according to Hay and Comins (1995), high-pitched voices, raised to be heard over the noise from children, merge into the background noise in a classroom.

In Laukkanen's (1990) study on the effect of manipulated auditory feedback, subjects increased their loudness while reading aloud with dark noise (low-pass filtration at 600 Hz), bright noise (high-pass filtration at 600 Hz) and white noise in headphones. According to Crandell and Smaldino (1995) (a) low-frequency noise appears to be the predominant noise in classrooms and has a greater effect on speech recognition than high-frequency noise. One may suppose that classroom noise may have a similar effect on the teacher’s voice as that obtained by masking the normal auditory feedback. Lane and Tranel (1971) showed that subjects change the loudness of their voices in direct relationship with the volume of noise against which they were speaking. Thus subjects increase their voice intensity by 1 dB for every 2 dB of background noise.

2.3.3.2. Effect of ambient noise on intelligibility of speech

In the 30 dB range ranging between 23-53 dB, measured in non-reverberant quiet rooms, the vowel sounds comprise 60% of the sound energy of speech but contribute only 5% towards the intelligibility of speech. In contrast, consonants represent 5% of the sound energy in speech but are responsible for 60% of the intelligibility of speech (Florida Department of Education, 1994). Rosenberg and Blake-Rahter (1995) point out that consonants are relatively weak and short in duration and are consequently more vulnerable to the damaging effects of ambient noise than most vowel sounds. The consonant sounds are also more vulnerable to poor acoustics as they include more high frequency energy, which is absorbed by most room surfaces. Due to upward spread of masking, the more powerful noise found in the low frequencies in classroom noise tends to mask the less powerful high frequency speech sounds (e.g., s, f, θ) that are critical for speech recognition (Rosenberg and Blake-Rahter, 1995). This is a matter for concern as low-frequency noise is assumed to be predominant in the spectra of noise found in classrooms (Crandell and Smaldino, 1995 (a)). As most of our ability to detect word differences, and ultimately to discern meaning, is derived from high frequency acoustical phonemes, pupils must be able to hear them. Indeed, Green et al. (1982) claim that approximately 50-70% of reading delays in elementary school children can be directly attributed to the effects of classroom noise. Lehman and Gratiot (1983) point out that attention and concentration in students increased when classroom noise was decreased.

Maintaining speech intelligibility seems to be possible under difficult conditions for achieving auditory feedback. Indeed, some utterances produced in noise have been shown to be more intelligible than utterances produced in quiet (Van Summers et al., 1988; Pekkarinen, 1988). It has been suggested that speakers try to maintain intelligible speech by altering their vocal production according to auditory feedback (Lane and Tranel, 1971).

2.3.3.3. Reverberation time in classrooms

Sound reflects off smooth surfaces such as walls, furniture, ceilings and windows. The reflection paths in a classroom can be many and each of these reflections will arrive at the listener within a very short time of each other. These reflections are called reverberant sound. Reverberation time (RT) refers to the amount of time it takes for a steady sound to decay 60 dB from its initial offset. The longer the reverberation time is, the more difficult it is to hear clearly. Large rooms with high ceilings, bare walls and bare floors, as many classrooms are, tend to have too long a reverberation time. Speech recognition in adult listeners is not reduced until RT exceeds approximately one second (Gelfand and Silman, 1979).

The American Speech-Language-Hearing Association (ASHA) recommends that RT shall not exceed 0.4 second for optimal listening conditions in classrooms. Recommended levels for reverberation time in unoccupied classrooms in the US, UK, Iceland and Finland range from 0.4 to 0.9 s. For young listeners reverberation time must not exceed 0.4 s if they are to obtain optimum communicative efficiency (Finitzo-Hieber, 1988; Crandell, 1991; Finitzo-Hieber and Tillman, 1978). However, the range of RT for unoccupied classroom settings is typically reported to be from 0.4 to 1.5 seconds (Crandell, 1991; Crandell and Smaldino, 1994; Finitzo-Hieber, 1988; Berg, 1993). For further information, see table in MacKenzie (1998).

2.3.3.4. Signal to noise ratio in classrooms

Signal to noise ratio (S/N ratio) is the relationship between the desired auditory signal and all unwanted background sound. It has been recommended that S/N ratio in children's learning environments should exceed 15 dB for maximum speech recognition (ASHA, 1995; Crandell, 1991; Finitzo-Hieber, 1988). For disabled children the ratio should be larger, at least 17-20 dB (Leventhall, 1998). In other words, the teacher's voice (the auditory signal) has to be 15-20 dB stronger than the classroom noise. A lower S/N ratio has been shown to lead to difficulties in speech recognition (Crandell and Smaldino,1995 (b)). However, according to Sanders (1965) S/N ratio in classroom condition is frequently less, even as poor as 1 - 5 dB.

Table 6 shows word recognition by children in varying S/N conditions (Finitzo-Hieber and Tillman, 1978). The evidence indicates that children with normal hearing are able to understand only 71% of what is being said in 6 dB S/N condition when reverberation time is 0.4 s. Amongst children with hearing impairment the figure is 52%. Children with normal hearing achieve only 54% monosyllabic word discrimination in commonly reported classroom conditions (S/N +6 dB, RT 1.2 s). Moncur and Dirks (1967) found that adults with normal hearing have the ability to recognise approximately 80% of monosyllabic words in 0.9 s RT conditions. Crandell and Smaldino(1995 b) state that in general speech recognition in adult listeners with normal hearing is not significantly affected until the speech and noise are at equal intensities.

Table 6. Average speech recognition scores of 12 normally-hearing students and 12 hard-of-hearing students in classroom conditions with various reverberation-time and signal-to-noise measurements. (From "Classroom Acoustics" by T. Finitzo-Hieber in Auditory Disorders in School Children (p 260) edited by R. Roeser and M. Downs, 1981, New York: Thiems Stratton. Copyright 1988 by Thieme Medical).

Reverberation time(s)	**Signal to noise ratio (dB)**	**Scores of normal hearing children**	**Scores of hearing impaired children**
0.4	+12	83%	60%
	+ 6	71%	52%
	0	48%	28%
1.2	+12	69%	41%
	+ 6	54%	27%
	0	28%	11%

It is suggested that the sum effect of reverberation and noise adversely affects speech recognition to a greater extent than when both effects are taken separately (Berg, 1993; Pekkarinen, 1988; Johnson, 2000).

2.3.3.5. Teacher – student distance

Classrooms are usually large, and sound loses its force according to the "inverse square law" (i.e., sound level decreases 6 dB for every doubling of distance from the sound source in a non-reverberant field) The sound which travels straight from the source to the listener's ear is called "direct sound", and for the best understanding of a message a substantial proportion of the acoustic energy of the voice must be received by the listeners as direct sound.

2.3.3.6. Critical distance

Because of the inverse square law, the direct sound field in a classroom is dominant only at distances close to the teacher (Crandell and Smaldino, 1995 (a)). Indeed, Harris (1979) stated that for ideal speech communication to take place the distance between the teacher and students should be 3 – 4 feet (about one meter) only.

The "critical distance" is defined as the distance where the indirect or reverberant field begins to dominate the listener's environment. According to Crandell and Smaldino (1995 (b)) the critical distance in a classroom of 150 m^3 in size with RT of 0.6 s would be approximately 3 meters from the teacher; "thus many, if not most, children in a classrooms will be in the indirect sound field". Leavitt and Flexer (1991) used Rapid Speech Transmission Index (RASTI) to estimate speech perception in a classroom. In RASTI, speech-like signals are used in ways that can be related to speech perception. The results pointed out that 83% of the speech energy was available to the listeners in the front seat but decreased to 55% in the centre of the back row. Crandell and Bess (1986) examined the speech recognition of 5-14 years old children in classroom environment with S/N ratio 6dB and RT 0.45 s. The mean speech recognition scores of 95, 71, and 60% were obtained at 6,12 and 24 feet (1.83, 3.66 and 7.32 meters, respectively). Crandell and Bess (1986) used monosyllabic words in their investigation into speech recognition of 20 children with normal hearing, aged 5-7 years old, in listening circumstances where S/N ratio was 6dB and RT 0.63 s. Mean word recognition scores of 82%, 55%, and 36% were obtained at 6, 12, and 24 feet, respectively. This means that pupils sitting in the middle of a class or further back may not be able to hear enough of what the teacher is saying to understand its content. However, Pekkarinen (1988, p57-76) found that sentences were perceived better than words in reverberant classroom conditions, so young children may recognise classroom speech better than the figures quoted above may suggest.

2.3.4. Students' ability to understand speech in the classroom

It is estimated that young children may spend as much as 60% of their school day involved in the listening process (Rosenberg and Blake-Rahter, 1995). According to Crandell et al. (1995) the child does not generally reach adult-like performance on recognition tasks in noise or reverberation until approximately 13-15 years of age; in particular, the ability to identify consonants in such conditions may not mature until late teenage years (Johnson et al., 2000). Adult listeners need fewer auditory clues to understand meaning, as they have more pre-existent knowledge and can thus reconstruct language from fewer phonemes. Young listeners may therefore not be as effective listeners as adults, especially in combined conditions (Pekkarinen, 1988; Johnson, 2000). According to information from the Acoustical Society of America young listeners require 2-3 dB higher S/N ratio than adults in conditions where there is background noise in order to obtain the same level of communication (Mac Kenzie, 1998). The children who are worst served by a poor acoustical environment, and need the best possible environmental conditions for listening, are those with handicaps, e.g., hearing problems, language disorders, developmental disabilities, articulation disorders, learning disabilities, or those learning through the medium of a language which is not their mother tongue (Crandell et al., 1995; Elliot, 1982; McCormick and Schiefelbusch, 1984; Flexer, et al. 1990). Such children have a lowered ability to identify the desired acoustic signal and demonstrate poorer speech recognition in classroom noise than children with normal learning abilities.

2.3.4.1 Hearing problems in children

Probably the largest group of handicapped children are those with temporary hearing loss due to otitis media. Crandell et al. (1995) state that between 76% and 95% of all children experience at least one episode of otitis media with effusion by the age of six years. Additionally, one third of all children suffer from persistent otitis media during their first 3 years of life, a vital time for speech and language development. According to Leventhall (1998), an increasing number of children are experiencing mild temporary hearing loss because of otitis media. He also states that it is estimated that 25-30% of children in kindergarten and first grade will not be able to hear normally on any given day. Hull (personal contact, 2000) has also pointed to an increase in hearing impairment amongst young high school students; he suggests that about 70% of these students may suffer from the early stages of hearing loss. ASHA studies (1995) have shown that 13% of a representative sample of children between the age of 6 and 19 had high frequency hearing loss and 7% low frequency loss of 60 dB or more. Dobie and Berlin (1979) showed that mild (20 dB) conductive hearing loss in children can limit their ability to understand brief utterances and/or interpret high frequency stimuli, particularly if the listening environment is not favourable. As can be seen from table 6, children of 8-12 years with hearing impairment obtained only one third accuracy in monosyllabic word discrimination in classrooms where the hearing conditions were S/N 6 dB and RT 1.2 s.

2.4. AMPLIFICATION IN CLASS

2.4.1. Sound field amplification systems

According to the literature, the use of amplification in classrooms for children with normal hearing seems to be virtually unknown, although amplification devices suitable for classroom purposes have existed for a considerable time. With the arrival of cordless microphones it is possible for a teacher to move around the classroom while using the amplification system. If the teacher wishes to teach an individual pupil it is possible for him or her to switch off the transmitter and so ensure that what is said is not heard by the whole class.

The equipment consists of a sender unit, made up of a cordless microphone and a radio transmitter, and a receiver unit consisting of a receiver and an amplifier. The microphone, worn on the chest or on a headband, is linked with a portable radio transmitter which can be clipped to, e.g., a belt. The receiver is linked to one or more amplifiers which amplify the sound to the level required. The amplifiers can be either portable, fastened to the wall or freestanding on the floor.

The cost depends on the quality and size of the equipment. Flexer et al. (1995) stated that if a high quality permanent sound system was installed (e.g., as used in theatres and public halls) the cost would run to thousands of dollars, whereas in school session 2001-2002 in Iceland, the cost of providing amplification equipment was between 1046 and 1395 euros per classroom.

2.4.2. The advantages and disadvantages of using sound field amplification

Until now it has not been the practice to amplify the teacher's voice in normal circumstances. However, a number of studies have investigated the effects of sound field amplification for non-handicapped children in classrooms. Qualitative results from questionnaires indicate that teachers appreciate the value of amplification. Indeed, teachers who have had the opportunity to make use of sound field amplification choose that in preference to other equipment such as overhead projectors, televisions, computers and filmstrip projectors (Allen, 1993). Evaluations by teachers indicate that amplification reduces vocal strain and voice fatigue (Sarff, 1981; Gilman and Danzer, 1989; Rosenberg et al., 1994). As can be seen in table 7 amplification seems to reduce vocal strain and vocal symptoms.

Table 7: A summary of studies on auditory feedback when using amplification.

Author	Subjects Fem.	Mal.	Method	Results
Chang – Yit et al. (1975)	5	1	Sidetone* amplification effect assessed over 5 days of testing.	Decreased vocal intensity.
Roy et al. (2002)	15		Use of Chatter Vox portable amplification device for several weeks.	Reductions in jitter, shimmer and Voice Handicap index scores.
Sapienza et al. (1999)	4	6	SPL examined during lecture in classrooms with and without amplification.	Amplification lowered SPL significantly (mean decrease 2.42 dB).

(Sidetone amplification = when the voice is amplified, the subject typically lowers his/her voice)*

Additionally, in Sarff's study (1981) with pupils aged 10 to 12, conducted over a period of three years, amplification enabled teachers to teach with fewer hesitations, repetitions or interruptions to the flow of the lesson. This is in line with Allen and Patton's (1990) results which indicated that teachers using amplification needed to repeat themselves less often.

To the best of my knowledge, up till now there has been little quantitative information about the effects of sound field amplification in teaching on such vocal parameters as SPL, F0 and spectrum in teachers' voices. It is known that speakers decrease their vocal intensity by 1 dB for every 2 dB of amplified vocal feedback (Lane and Tranel, 1971). Sapienza et al. (1999) demonstrated that the use of amplification significantly lowered SPL (mean decrease 2.42 dB) in 10 teachers' voices while lecturing for 15 minutes in an unoccupied classroom. In Rosenberg and co-workers' (1994) study on 855 students in 40 classes (20 amplified and 20 control) teachers using amplification showed an average gain of 7.52 dB and in Flexer et al's (1990) study amplification increased the intensity of the teacher's voice by 10 dB.

Flexer et al. (1995) state that the goal of a sound-field amplification system is to provide an even and consistent S/N ratio improvemnt eof approximately 10 dB throughout the learning area. Research has demonstrated the efficacy of sound field amplification in improving students' speech recognition, academic achievement, learning behaviour and ability to receive instruction (Sarff ,1981; Gilman and Danzer, 1989). Crandell (1994) showed that field amplification at a speaker-listener distance of 12 and 24 feet significantly increased speech perception in children for whom English was not the native language. Other findings have reached the same conclusions among students with normal hearing in classroom conditions of S/N ratio 6dB and RT 0.6 s (Crandell and Bess, 1986;

Crandell, 1993). Flexer et al. (1990) studied speech recognition of 9 developmentally handicapped children in a primary-level class. Results showed that errors in a Word Intelligibility by Picture Identification test (WIPI) dropped by approximately two thirds when amplification was used. Additionally, it was observed that the children were more relaxed and answered more quickly in amplified conditions. Flexer, Millin and Brown (1990) showed how children with developmental disabilities made significantly fewer errors in a word identification task when the teacher used amplification. Lehman and Gratiot (1983) demonstrated that a reduction in classroom noise had a significant effect in increasing concentration, attention and participatory behaviour in 9 children with developmental disabilities. Additionally, it was observed in Flexer et al's (1990) study that the children were more relaxed and responded more quickly in the amplified condition. Findings have also shown that amplification improves the classroom behaviour of young children (Palmer, 1998; Allen and Patton, 1990). Indeed, findings have indicated that young children make much more progress when amplification is used (Sarff, 1981). The disadvantages of using amplification equipment appear to lie principally in a) the failure of teachers to tune the system properly due to a lack of the required knowledge and b) an inappropriate amplification system being chosen for use in the classroom (listed below).

Advantages

Summarised research results identifying the advantages of amplification systems in classrooms (Rosenberg and Blake-Rahter, 1995 p108-109)

Reduced vocal strain and fatigue for teachers
Improved academic achievement, especially for younger students
Decreased distractibility and increased on-task behaviour
Increased attention to verbal instruction and activities and improved understanding
Decreased number of requests for repetition
Decreased frequency of need for verbal reinforcement to facilitate test performance
Decreased test-taking time
Improved spelling ability under degraded listening conditions
Increased sentence recognition ability
Improved listening test scores
Increased language growth
Increased preference by teachers and students for sound-field FM amplification in the classroom
Improved ease of listening and teaching
Reduced special education referral rate
Increased seating options for students with hearing loss
Cost-effective means of enhancing the listening and learning environment

Disadvantages

Summarised research results identifying the disadvantages of amplification systems in classrooms (Flexer et al, 1995 p126)

Too much amplification
An inappropriate amplification system for the classroom
Failure to be of value in excessively noisy or reverberant classrooms
Insufficient technical knowledge in the teacher, causing, e.g., acoustical feedback when the teacher speaks too close to the microphone, or sets the gain or the volume of the system too high.

Although results are available on both teachers' and students' reactions to the use of amplification in the classroom as well as teachers' subjective sensations, to my knowledge no results have so far been published on how amplification may affect vocal parameters during the working day.

3. AIMS

The aims of this study were threefold:
- to obtain more detailed acoustic information about the effects of amplification on speech;
- to obtain, by following the changes in speech parameters during a teacher's working day, more information about the effects of vocal loading;
- to obtain via questionnaires information that could help to improve the amplification systems used in classrooms;

Seven questions were addressed:

To reach the first aim:
1. Does amplified and damped auditory feedback lower the average fundamental frequency (F0), and sound pressure level (SPL) in text reading? (Study I)
2. Does the use of amplification lower F0 and SPL of the teacher's classroom speech? (Study II)
3. Is there a change in vocal parameters and in perceptual voice quality when amplification is used in classrooms as compared to non-amplified conditions? (Studies IV and V)
4. Does the use of amplification in classrooms diminish the teachers' symptoms of vocal fatigue? (Study III)
5. Does the use of amplification in classrooms make it easier for pupils to follow teaching? (Study III)

To reach the second aim:
6. Is there a change in vocal parameters (F0, SPL, phonation time, long-term-average spectrum) and in perceptual voice quality during a teacher's working day? (Studies IV and V)

To reach the third aim:
7. What advantages and disadvantages of the use of amplification in classroom will be reported by the teachers and students? (Study III)

4. SUBJECTS AND METHODS

4.1. SUBJECTS

In Study I the subjects were six Finnish females (mean age 33 years) without any known voice or hearing problems.

In Study III the subjects were 33 teachers (26 females, 7 males) and their 791 students (446 females and 345 males) from three Icelandic educational institutions. The institutions consisted of a university, two schools from the Icelandic basic school system for learners aged 6 - 15, and a junior college for learners aged 16 - 20. Of the learners, 174 females and 207 males came from the basic school system, 221 females and 108 males came from a junior college and 51 females and 30 males from a university.

The average numbers of pupils in the classes were 19 (range 15 – 28) in the basic school system, 22 (range 18 – 22) in the junior college and 53 (range 33 – 76) in the university. The classrooms were of different sizes ranging from 40 m^2 in the basic school system to 158 m^2 in the university; a gymnastic hall of 175 m^2 was also used in the study. The mean age of the teachers' group was 45 years (range 27 – 64 years). The mean teaching experience was 16 years (range 1 – 32 years). Nine percent were smokers. Half of the teachers reported that they suffered from vocal fatigue.

In Studies II, IV and V the subjects were three females and two males (mean age 51, range 41 - 63 years) taken from the group of 33 teachers in Study III. All subjects had a long teaching experience (10 - 31 years). Two of the females taught the youngest pupils in the basic school system. The others worked in a junior college. All were non-smokers and all suffered from multiple vocal symptoms (3 or more symptoms) that mostly occurred during the term and therefore seemed to be work-related. One female suffered from asthma and allergies. Because of non-organic dysphonia, she had been given 8 voice lessons by a speech pathologist. One female suffered from a slight hearing problem. A clinical examination of each subject was performed before the experiment started. No pathological changes were found in their vocal organs.

4.1.1. Vocal symptoms of the teachers (III)

Background information was collected via 19 multiple choice questions (see Appendix 1). The subjects reported on the prevalence of their vocal symptoms on a scale of 1 – 5 (1 = Hardly ever, 2 = Seldom, 3 = Sometimes, 4 = Often, 5 = Almost always). Replies for choices 1 – 2 were interpreted as “no” and for choices 3 - 5 as “yes”). Stressfulness of teaching was rated on a scale 1 – 8, where readings for stressfulness were estimated on an ascending scale of 1 to 8. Results found that scores of 6 - 8 should be regarded as indicating stress.

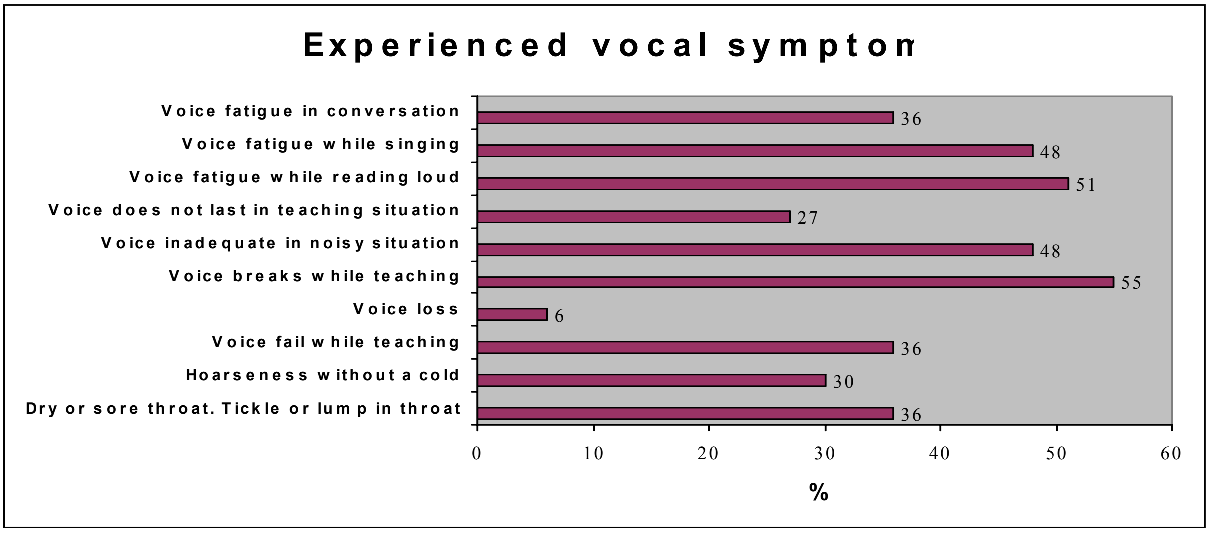

Fig 3. Self reported vocal symptoms of 33 teachers.

As can be seen in fig. 3 about half of the group experienced vocal fatigue while singing and reading aloud, voice breaks while teaching and voice inadequacy in noisy situations. One third complained of hoarseness without a cold, vocal fatigue during conversation, failure of the voice to last out a teaching session and voice failure while teaching. One third complained of discomfort in the throat: dryness, tickles, lumps, sore throat.

More than half of the group (64%) reported that they experienced the symptoms while teaching. None reported on having experienced symptoms during the summer holidays. Thirty nine percent of the teachers reported they found teaching stressful.

4.2. METHODS

4.2.1. Voice samples

4.2.1.1. In laboratory conditions (I)

4.2.1.1.1. Amplified feedback

The subjects read aloud from a text consisting of 133 words without any /s/ phonemes while wearing headphones (Sennheiser HD 530II). The signal picked up by the microphone was fed through an amplifier (an extra DAT recorder (TASCAM DA 20MKII)) and fed back to the headphones so that the subjects heard their own voices louder. The subjects set the level of the amplification as they found it most comfortable to listen to. The amplification was adjusted with the phone control button of the DAT recorder by the subjects themselves. The subjects read the text twice in the morning and twice in the evening, on each occasion reading first without amplification and then with amplification. These readings were repeated on two further occasions, the intervals between the readings varying from one week to three months. In total there were thus 12 samples recorded under normal circumstances and 12 recorded with amplified feedback**.**

One microphone (Brüel and Kjær 4164) was at a distance of 40 cm from the subject's mouth. A similar microphone was placed inside the headphones to record the amplified signal. The signals were calibrated (Brüel and Kjær sound level calibrator type 4230) for sound pressure level measurement. The reason for using two microphones was to study how loudly the subjects wanted to hear their voices.

4.2.1.1.2. Damped feedback

The procedure was the same for the damped feedback test as for the amplification test; the subjects recorded 12 samples under normal circumstances and 12 with amplification. Thus, for the damped feedback test the subjects recorded 12 samples under normal circumstances and 12 with foam plastic earplugs. The headphones were replaced by earplugs for the damped feedback test. The damping effect of the foam plastic earplugs varied at different frequencies, increasing gradually from 22.3 dB at 63 Hz up to 40.4 dB at 8000 Hz.

4.2.2. In field conditions (II, IV, V)

In Studies II, IV and V the recordings took place in the classrooms routinely used by the teachers in their daily work. The classrooms were on average 55 m^2 in size, ranging from 38 to 70 m^2. The length of the working day ranged from 5 lessons (each lasting 40 minutes) common in the basic school system to 9 lessons taught by one of the teachers at the junior college. From their timetables, the subjects chose for research purposes the scheduled working day which they considered to be the one which was most vocally demanding. On that day the teacher's classroom speech was recorded in the first and last lesson, each lasting ca 35 – 40 min, first without amplification and then on the same day a week later with amplification. The subjects had used amplification in class during that week (a WL 184 lapel condenser chest microphone and an ETGS transmitter and receiver; an Anchor AN 100, or a Trace Elliott 30 Watt combined amplifier and a portable loudspeaker). The portable loudspeaker was placed on a shelf or a desk in front of the class. As the system was cordless the teacher could walk freely in the classroom, turning the system off if needed. The amplification level was chosen by the teacher. When amplified speech was recorded the subjects had 2 microphones - one chest microphone (WL 184 lapel condenser) for amplification and one (Senheisser MK 2) attached to a headset for recording at a distance of 7 cm from the mouth. The transmitter which transferred the sound from the microphone to the receiver was located on a belt worn by the teacher. The DAT recorder was carried in a bag hanging from the waist of the teacher.

4.2.3. Analyses of the speech samples

4.2.3.1. Fundamental frequency, sound pressure level (I, II,IV) and phonation time (II)

In Studies II and IV the speech material analysed consisted of three 4 minute samples taken from the very beginning, middle and end of the first and last lesson without and with amplification. F0 and SPL were measured with an analogue system (F-J electronics). Filter limits for female voices were 300 Hz and 70 Hz with a slope of 36 dB/octave. For male voices the filter limits were 200 Hz and 40 Hz. Integration time was 10 ms for SPL signal.

Analyses were made with a microcomputer (Apple Machintosh Quadra 950) equipped with three extension boards (National Instruments). By using the LabVIEW 2 graphical programming system the signal was divided into 4 different channels - two channels for the SPL of two different integration times, one for F0 and one for audio signal. The sampling rate for each signal was 5 kHz. The limits employed by the analysis program were 61 – 100 dB for the SPL and 140 – 450 Hz for females' F0 and 70 – 250 Hz for males' F0. The phonation time - i.e. the time during which the vocal folds were vibrating - was calculated from the F0 signal.
In Study I, F0 and SPL were measured with a computerized signal analysis system called the Intelligent Speech Analyser (ISA) developed by Raimo Toivonen (M.Sc.Eng.). The alpha ratio was calculated by dividing SPL at the range 1-10 kHz by the SPL of the range 50 Hz-1 kHz (Frøkjær – Jensen, 1976). As the alpha ratio illustrates the frequency distribution of sound energy it was used to study the acoustic quality.

Changes in F0 were transferred in semitones using the formula 39.86 x log (F0/16.35) in order to make male and female voices comparable.

4.2.3.2. Long- term- average- spectrum (I,V)

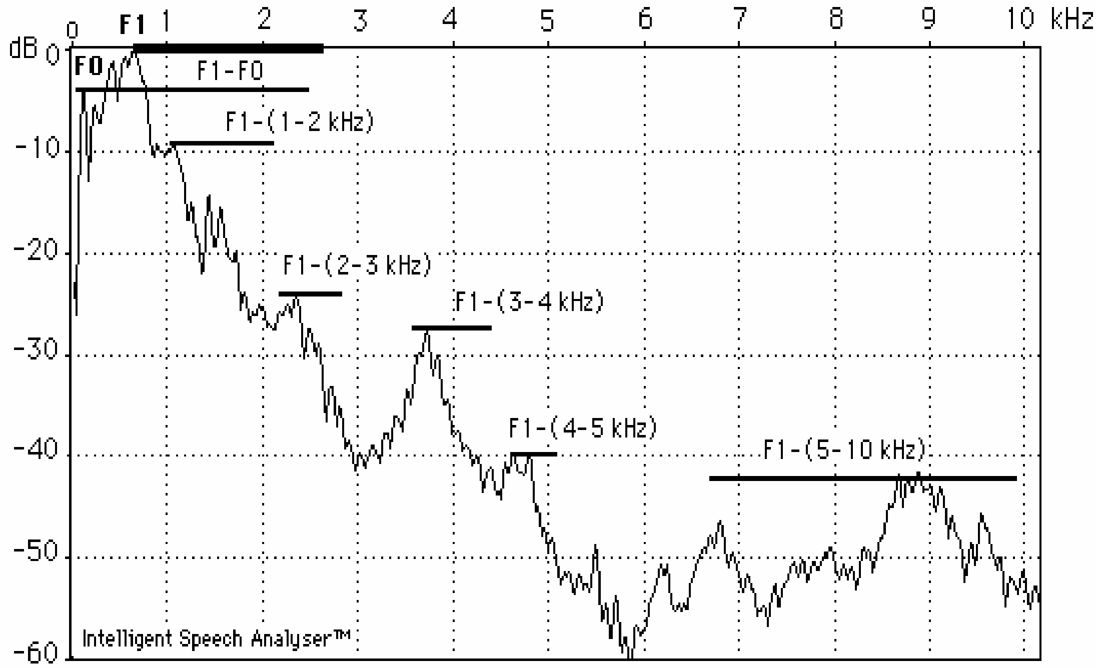

Fig. 4: Measurements of level differences in Long-term-average-spectrum. Level differences were calculated between the strongest component (typically first formant, F1) and the range of fundamental (F0) as well as between F1 and the strongest component of the ranges of 1-2 kHz, 2-3 kHz, 3-4 kHz, 4-5 kHz and 5-10 kHz.

In Study V a Long-term-average-spectrum (LTAS) analysis was made with ISA. In Study I the spectrum was studied by calculating SPL at different frequency ranges with ISA. Recordings were analysed in Study I. In Study V three samples of 2 minutes duration taken from the very beginning, from the middle and from the end of the first and the last lesson of a working day (i.e. a total of 6 minutes of classroom speech) were analysed from the first and from the last lesson. Voiceless sounds and pauses were excluded automatically from the signal. Background noise was not excluded since exclusion was not regarded as necessary (see below) and would have required very strenuous and time-consuming manual editing

SPL was calculated of the following frequency ranges with ISA or the peak amplitude of these frequency ranges was measured manually from LTAS (see Fig. 4) to describe the spectral structure numerically:

F0 (measured mean of F0 ± 50 Hz).

the first formant (F1) region; 300 – 1000 Hz

50 Hz -1 kHz
2 – 5 kHz

5 – 10 kHz
1 – 10 kHz

To illustrate the sound energy distribution more clearly the differences between the SPL values of the following frequencies were calculated:

the range of F1 and the range of F0 (F1-F0) (I)

the range of F1 and 2 – 5 kHz region (I,V)

the range of F1 and 5-10 kHz region (I,V)

Alpha ratio was calculated by dividing the SPL of the range 1 – 10 kHz by the SPL of the range 50 Hz – 1 kHz. (I)

To study the effect of background noise (children's chat) on LTAS a test was made as can be seen in figure 4. As can be seen SPL in the teacher's voice (underlined, bold) was considerably stronger than SPL in the background noise. Therefore, the background noise was ignored.

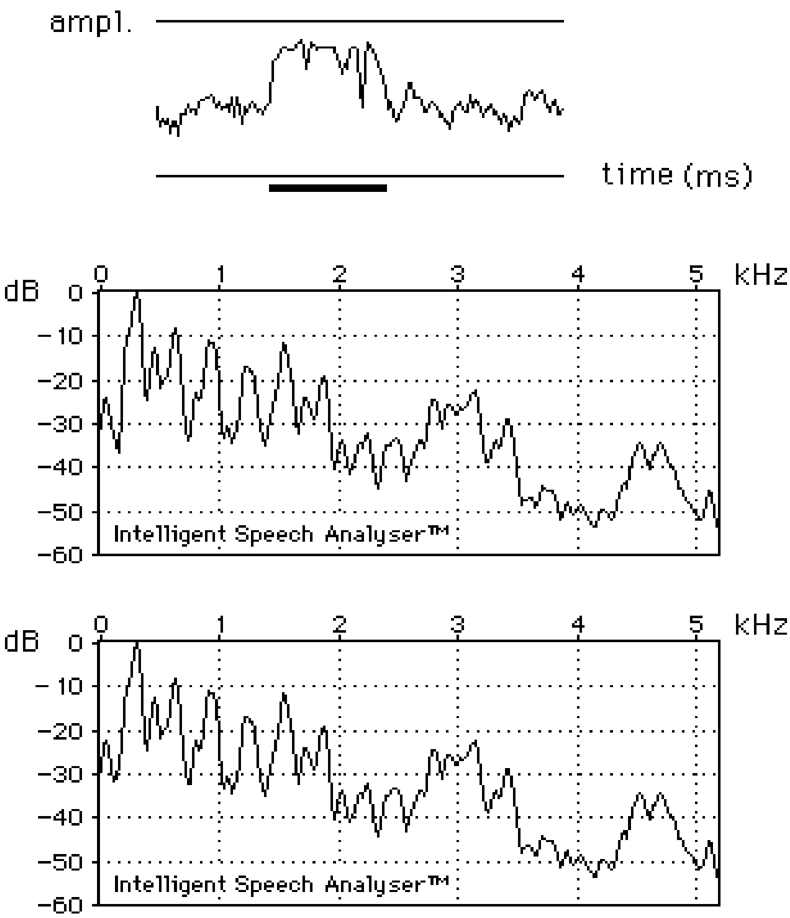

Figure 5. Top: Time-amplitude presentation of teacher's speech (marked with underlined bold line) and background noise (children's chat). Teacher's speech 22 dB stronger in SPL. Middle: LTAS of a female teacher's speech without background noise. Bottom: LTAS of the teacher's speech with background noise (children's chat).

LTAS analysis was performed on a sample in which the teacher spoke without background noise (black line below the time-amplitude presentation). Thereafter a LTAS was made from a longer sample in which there was classroom chat (the whole signal shown in the time-amplitude presentation). A particular section of the recording was chosen because there was particularly strong background noise in the classroom. It can be seen that the two LTAS are identical. Thus, the background noise did not seem to affect the form of LTAS. It is known that the form of the LTAS is determined by the strongest components of the signal. In this case, due to the short mouth-to-microphone distance (7 cm) the SPL of the teacher's voice clearly exceeded that of the background noise (in the example the teacher's voice was 22 dB stronger than the background noise).

4.2.3.3 Perceptual analyses (V)

Two professional voice trainers evaluated perceptually the same two minute voice samples that were used for the LTAS analyses. The samples were randomised on the tape so that the listeners did not know whether a sample was recorded with or without amplification, or whether it was recorded in the first lessons or in the last lesson. However, all the samples of the same subjects were replayed in a row. The listening test was conducted in free field in a damped room using DAT recorder and a Genelec Biamp loudspeaker. The listeners evaluated the voices on a 10 cm Visual Analogues Scale (VAS). The characteristics evaluated are listed in table 8:

.

Table 8. Characteristics evaluated with VAS scale

Overall voice quality	Definition
Vocal fatigue	Monopitched, tensed, breathy and hoarse voice (Colton and Casper, 1990).
Breathiness	Audible escape of air through the glottis due to insufficient glottal closure (Hammarberg, 1992).
Strainedness	Voice sounds strained as if the vocal folds are compressed during phonation (Hammarberg, 1992).
Asthenity	A high-pitched female-like weak voice (Isshiki, 1969).
Cloudiness	Possibly a perceptual sign of laryngitis or vocal fatigue. Damped, not clear voice. Poor condition of voice.
Clarity	Opposite to cloudiness: a clear and audible voice. Good condition of the voice.
Vocal fry	Low-frequency periodic vibration (Hammarberg,1992).
Voice breaks	Intermittent frequency breaks (Hammarberg, 1992).
Throat clearing	
Pitch	The chief auditory correlation of fundamental frequency (Hammarberg, 1992).

Average voice quality was evaluated on a scale from poor (-3) to excellent (+3). Pitch was evaluated either as felt to be appropriate for the speaker and the task, or as too low, or too high.

One of the two listeners evaluated the samples twice in order to calculate intra-observer reliability for the results.

4.3. METHODS FOR STUDY III

4.3.1. Questionnaires for the teachers

The teachers answered two questionnaires at the end of the research period. One questionnaire was for background information, which was discussed in Chapter 4.1.1. The second questionnaire, containing 13 multiple choice questions, registered the teachers' views on the use of amplification in teaching. The questions concerned the effects of amplification on voice production, vocal symptoms, fatigue in the vocal mechanism, general fatigue, progress of the lessons and students' attention. Questions about possible disadvantages arising from the use of amplification were also included. Choices given for each effect were ‘considerable - a fair amount - not much - none’. See Appendix 2.

4.3.2. Questionnaire for the pupils

Students aged 10 years and older (n=664) received a questionnaire on the advantages and disadvantages of using amplification, such as its effects on their capacity to pay attention in a listening situation, on teachers’ diction, and in general whether the students found the amplification annoying or not. Choices given for each effect were ‘very much - much - a little - not’. The students were also asked to describe freely in one to two sentences the advantages and disadvantages arising from the use of amplification. The questionnaires were given out during the last lesson taught with amplification and were filled in immediately; this was done to ensure the best and most accurate response. See Appendix 3.

Students aged 6 – 9 years (n=127) were individually and orally asked 2 questions:
Did you like it when your teacher used an amplification system? Why?

4.4. STATISTICAL METHODS

Student's t-test was used to study the significance of differences between vocal parameters measured (1) with and without amplification and (2) in the first and the last lesson. Spearman correlation was used to study (1) intra- and inter- observer reliability in the listening evaluation and the relation between (2) acoustic and perceptual results and (3) various perceptual parameters.

5. RESULTS

5.1. QUANTITATIVE RESULTS

5.1.1. Effects of amplified and damped feedback on F0, SPL and phonation time (Studies I, II and IV)

5.1.1.1. In laboratory conditions (I)

Recordings were taken of six females reading aloud while hearing their own voices amplified in headphones. These recordings were analysed. The results suggested that hearing the voice amplified while reading lowered the F0 and SPL significantly. When auditory feedback was damped with earplugs (table 9) the F0 and SPL values were also significantly lowered compared to recordings without amplification.

Table 9. Mean fundamental frequency (F0) and sound pressure level (SPL) of six females for reading with and without amplification and damping and the statistical significance of the difference (paired samples t – test).

A.	F0 (Hz)			SPL (dB)		
	with	**without**	**sig.**	**with**	**without**	**sig.**
Amplification(n=72)	171	174	p< 0.001	66.1	68.4	p< 0.001
Damping(n=72)	180	182	p= 0.020	66.0	66.5	p= 0.006

During amplified auditory feedback the changes in F0 and SPL correlated positively with each other (r 0.64, p<0.001). Maximum decrease in F0 was 1 semitone and that in SPL was 6 dB compared to recordings without amplification. During damped feedback there was a weak negative correlation between F0 and SPL changes (r-0.27, p=0.020). The maximum decrease in F0 was 2 semitones and that of SPL was 4 dB compared to recordings without amplification.

5.1.1.2. Amplification in classrooms (II, IV)

5.1.1.2.1. F0 and SPL

Results from 4 minutes samples (taken from the very beginning, middle and end of a lesson. Both the first and the last lessons were included) showed that amplification lowered significantly F0 and SPL both for females and males (table 10).

Table 10: Mean values of fundamental frequency (F0) and sound pressure level (SPL) in teachers' classroom speech with and without amplification and the statistical significance of the difference (paired samples t –test).

	F0 (Hz)			**SPL (dB)**		
	with	**without**	**sig.**	**with**	**without**	**sig.**
females (n=3)	276	284	p= 0.002	66.1	68.4	p< 0.001
males (n=2)	135	146	p< 0.000	66.0	66.5	p= 0.006

5.1.1.2.2. F0 time (II)

Amplification seemed to decrease and increase the phonation time for the genders in the 4 minute samples, but the changes were statistically non-significant (table 11).

Table 11: Mean values of phonation time (F0 time in percentages of 4 minutes total sample duration) in teachers' classroom speech with and without amplification: the difference caused by amplification was statistically non-significant at 5%level (paired samples t-test).

	with	without
females (n=3)	88.5%	82.8%
males (n=2)	70.9%	84.0%

5.1.2. Effects of amplified and damped auditory feedback on Long-term-average-spectrum (I, V)

5.1.2.1. In laboratory conditions (I)

Level difference between the region of F1 and the region of F0 (F1-F0) decreased significantly with amplification, suggesting a relatively stronger fundamental. The spectral slope became steeper (weaker overtones) as shown by a decrease in alpha ratio (by dividing the SPL of the range 1 – 10 kHz by the SPL of the range 50 Hz – 1 kHz) when the subjects heard their voices amplified through headphones (p< 0.001) (table 12).

Table 12: Mean Long-term-average-spectrum (LTAS) characteristics for normal reading without wearing headphones and while hearing own voice amplified through the headphones (left) and normal reading before wearing earplugs and for reading while wearing earplugs (right) and the statistical significance of the difference at 5% level (paired samples t – test). NS= non-significant.

A.	**normal (n=72)**	**amplified (n=72)**	**sig.**	**normal (n=72)**	**earplugs (n=72)**	**sig.**
F1-F0	12.7	11.7	p<0.001	13.3	13.3	NS
F1 (2-5 kHz)	19.0	18.9	NS	18.7	18.6	NS
F1 (5-10 kHz)	29.3	28.7	p=0.005	29.4	29.4	NS
Alpha ratio	0.85	0.83	p<0.001	0.85	0.86	NS

5.1.2.2. Amplification in classrooms (V)

In general the slope of the LTAS was steeper when amplification was used. The difference between ordinary condition and amplification was prominent in the first lesson (table 13).

Table 13: Mean Long-term-average-spectrum (LTAS) values for the first and last lesson without and with amplification and the statistical significant of the difference at 5% level (paired samples t-test) NS= non-significant.

	First lesson			**Last lesson**		
kHz	**with amplification**	**without amplification**	**sig.**	**with amplification**	**without amplification**	**sig.**
1-2	-13.6	-10.1	p= 0.004	-11.2	-10.9	NS
2-3	-22.6	-20.9	NS	-20.5	-20.4	NS
3-4	-27.2	-24.1	p= 0.005	-25.5	-24.1	NS
4-5	-33.4	-29.8	p= 0.022	-29.9	-29.6	NS
5 -10	-40.8	-35.9	p< 0.001	-40.8	-34.5	p= 0.040

5 1.3. Working-day-related changes (IV, V)

5.1.3.1. Changes in F0 and SPL (IV)

There was an increase in F0 and SPL during the teachers' working-day whether amplification was used or not. This increase was larger and statistically significant when amplification was used (table 14). For each subject there was a general trend that F0 was higher during the last lesson but there were also relatively large changes in F0 during the lesson. A positive correlation between F0 and SPL was found in both conditions (r 0.50, p=0.027 in normal conditions; r 0.50, p=0.005 with amplification) (table 14).

Table 14: Mean value of fundamental frequency (F0) and sound pressure level (SPL) in first and last lesson without and with amplification and the difference with statistical significance at 5% level (paired samples t-test). NS= non-significant.

	Without amplification (n=5)				**With amplification** (n=5)			
	First lesson	**Last lesson**	**Diff.**	**Sig.**	**First lesson**	**Last lesson**	**Diff.**	**Sig.**
F0	227	231	4	NS	213	225	12	0.010
SPL	75.4	76	1.1	NS	73.7	75.8	2.0	0.020

5.1.4. Changes in spectrum (V)

The spectral slope became seemingly less steep in the course of the teachers' working day when amplification was used but the difference between the two conditions was non-significant (fig. 6, 7). Without amplification, a similar trend could be seen at 5 – 10 kHz (fig. 6). No significant changes were observed in spectral tilt between first and last lesson in ordinary conditions (fig. 6). During amplification the slope decreased significantly (p=0.045) at the ranges of 1-2 kHz, (p=0.038) at the ranges of 2–3 kHz, (p=0.012) at the ranges of 4-5 kHz and (p=0.020) at the ranges of 5–10 kHz (fig. 7).

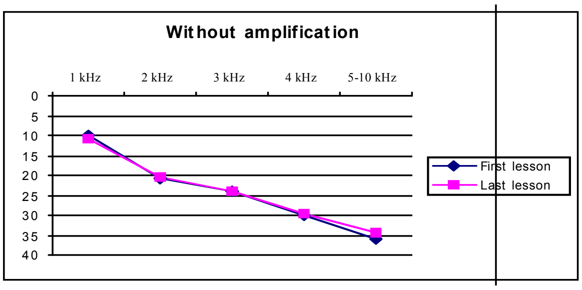

Figure 6. Average Long-term-average-spectrum (LTAS) values in 5 subjects in first and last lesson without amplification

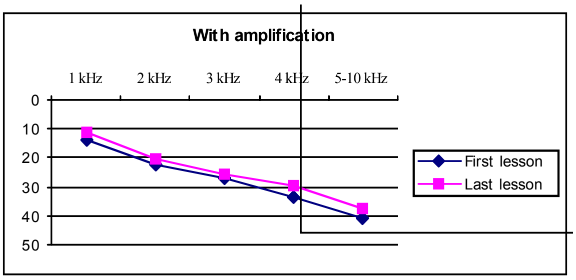

Figure 7: Average Long-term-average-spectrum (LTAS) values in 5 subjects in first and last lesson with amplification

5.1.4.1. Gender related changes in Long-term-average-spectrum (V)

In ordinary conditions no significant differences were seen in the results for LTAS between the genders. During amplification the two males showed somewhat different results from the females; the spectral tilt in the male voices decreased less or increased at some ranges during the working day.

Table 15. Mean differences in Long-term-average-spectrum (LTAS) characteristics between the first and last lesson (last lesson value minus first lesson value) with and without amplification for females (n=3) and males (n=2). Mean level differences between the strongest component in the LTAS and the strongest components between 1-2 kHz, 2-3 kHz, 3-4 kHz, 4-5 kHz and 5-10 kHz. Significance of the difference between females and males (paired Student's t-test) is given at 5% level of significance. NS = non-significant (p > 0.050).

	1-2 kHz	**2-3 kHz**	**3-4 kHz**	**4-5 kHz**	**5-10 kHz**
With Amplification.					
Females	3.9	4.1	3.5	5.7	6.5
Males	-2.1	1.2	-0.5	1.7	0.9
Sig.	0.033	0.032	0.034	NS	NS
Without Amplification					
Females	0.1	-0.1	0.4	-0.9	1.7
Males	0.04	-0.9	-1.2	0.03	-1.0
Sig.	NS	NS	NS	NS	NS

5.2. QUALITATIVE RESULTS (III, V)

5.2.1. Teachers' opinions on amplification in classroom (III)

5.2.1.1. Advantages

The large majority, some 91% of the 33 teachers, agreed that the use of an amplification system was beneficial both for voice and for communication in class. Amplification made voice production easier (97%), decreased vocal symptoms and fatigue in vocal mechanism (88%), decreased fatigue in the body (61%) and reduced the need for repetitions (82% of the teachers stated they needed to repeat themselves when not using amplification, in comparison with 9% when using amplification). Additionally, teachers agreed that students' performance was better because concentration was improved

5.2.1.2. Disadvantages

The teachers described briefly what they found disadvantageous while using amplification. One third of the teachers reported that they lacked sufficient skills in installing and using the amplification system correctly, one fifth of the group declared they found it inconvenient (e.g., it was difficult to transport the equipment between classrooms) and one fifth felt that there were no, or few, disadvantages. One fourth did not reply.

5.2.2. Students'/pupils' opinions on amplification in classroom (III)

5.2.2.1. Advantages

Of the 664 students who were given a questionnaire 528 returned answers (316 girls and 212 boys). The most commonly cited advantages (77-87% of all respondents) were *listening was easier, it was easier to hear through class chatter, and easier to follow the lessons* (fig. 8).

About half of the group (between 45% and 63%) noted that there was *less class chatter*, *fewer repetitions* by the teacher, and that it was *easier to concentrate* on the lessons. Sixty six percent of the students declared that they would remind their teacher to use the amplification if he or she forgot to turn it on.

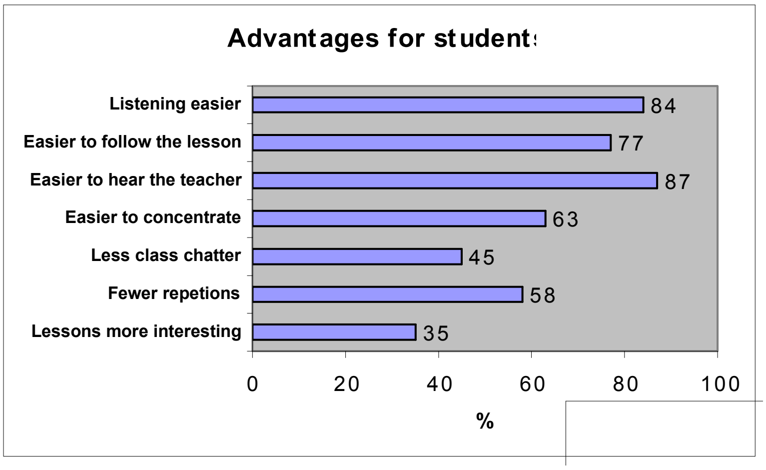

Fig 8. Opinions of 528 students on amplification in class.

Of the students' free comments on the teacher's use of amplification, most (87%) statements were to the effect that they could *hear better* (fig. 8). Among the youngest pupils (6-9 years of age) the percentage was more than 95%

5.2.2.2. Disadvantages

One third of the learners' group found *excessively loud sound from the system* and one fifth of the group found the *amplification annoying.* Of the students' free comments concerning disadvantages, most concerned *technical problems* or *lack of technical skill* of the teachers.

5.2.3. Perceptual evaluation of the teachers' voices (V)

5.2.3.1. Voice quality with and without amplification in classroom

Voices were perceived as significantly better in quality (p=0.004), less strained (p=0.029), less rough (p=0.027), less asthenic (p=0.043) and with fewer voice breaks (p=0.030) when amplification was used. On the other hand, there were no significant perceptual differences in pitch, breathiness, clarity, vocal fry, clearing and fatigue between the two conditions. Intra-observer consistency was satisfactory for all characteristics (r>0.50, p<0.001) except for vocal fry and vocal fatigue. For roughness intra-observer consistency was found low (r 0.42, p=0.012). Intra-observer consistency was satisfactory for pitch, vocal fry and clearing, whereas there was very little consistency for roughness, asthenity, breathiness, clarity and vocal quality.

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5.2.4.2. Changes in voice quality during working-day

No significant difference was found in changes in perceived voice quality during a teacher's working day except a small tendency for less asthenity while amplification was used (p=0.100).

5.2.4.3. Correlation between perceived voice quality and acoustic analyses.

Table 16 shows that voice quality correlated negatively with spectral slope, indicating that voices with steeper slope (weaker overtones) were perceived better. That is most likely due to the fact that strainedness correlated positively with spectrum slope.

Table 16: Spearman correlations, statistically significant at 5% level, between perceived voice quality and results of acoustic analyses. n=5.

		1-2 kHz	2-3 kHz	3-4 kHz	4-5 kHz	5-10 kHz
Quality	r	-0.41	-0.35	-0,47	-0.39	-0.44
Significance	p	0.001	0.007	0.000	0.002	0.001
Strainedness	r	0.49	0.47	0.32	0.59	0.45
Significance	p	0.000	0.000	0.013	0.000	0.000
Breathiness	r	-0.29	-	-	-	-
Significance	p	0.032	NS	NS	NS	NS
Vocal fry	r	-0.41	-	-0.14	-0.55	-0.53
Significance	pr	0.002	NS	NS (0.071)	0.000	0.000

6. DISCUSSION

It is well documented that outside factors such as poor acoustics, background noise and too great a distance between the teacher and the students affect both the voice of the teacher and the student's capacity to hear properly what is being said (Markides, 1986; Pekkarinen and Viljanen, 1990; Vilkman, 1996; Crandell and Bess, 1986; Pekkarinen, 1988).

The aim of this study was to discover whether amplification in the classroom might benefit teachers and students and, if so, what form these benefits might take. As the teachers participated voluntarily in the research, an interesting question was posed. Why did they wish to try amplification? Was it perhaps because of poor vocal health? If so, the results may not be typical for teachers in general. However, the background information from the 33 subjects in this research indicated that they were not suffering more acutely from vocal symptoms than their colleagues in other countries have in general reported (e.g., Sapir, 1993). This sample thus seems to be representative of the teaching profession. Additionally, according to questionnaire results from this study, reported symptoms seem to have been due to work-induced vocal load since no subject complained of any vocal symptoms during the summer vacation. These results bear out the results of Sala et al. (2001), who found during research into vocal symptoms of teachers in a day care centre that most complaints were reported during working hours, while no complaints of any vocal symptoms were reported during vacations.

Apart from their readiness to volunteer, the group of teachers had little in common: their ages, gender, teaching experience, their teaching methods and teaching environments, the size of the classrooms and the numbers and ages of students in class were all different. The purpose of this study was to obtain a varied selection of subjects so that although the number of the subjects was limited, they formed a representative group. It can also be regarded as advantageous that teachers showing voice symptoms were included in the sample, since it is precisely these teachers who would appear to have most to gain from amplification.

In Studies II, IV and V both female and male voices were quantitatively examined. F0 and SPL were examined in Studies II and IV, and spectrum characteristics in Study V. In some earlier field studies on teachers' vocal behaviour the female voice has been the principal focus (Rantala et al., 1994; Ohlson, 1988; Pekkarinen et al., 1992). As far as we know no studies have been made on male voices under working conditions in classrooms. Comparable research results on voice parameters in males must therefore be sought amongst males who were not teachers (Novak et al., 1991; Lauri et al., 1997).

6.1. CHANGES IN FUNDAMENTAL FREQUENCY, SOUND PRESSURE LEVEL AND SPECTRUM

6.1.1. Changes during amplified and damped auditory feedback in laboratory conditions (I)

6.1.1.1. Fundamental frequency and sound pressure level

Amplified auditory feedback lowered significantly F0 and SPL. This is much in line with earlier studies where amplified feedback has been studied in laboratory and field conditions (Laukkanen, 1990; Sapienza, 1999).

It is well known that speakers tend to increase the loudness of speech with the ambient noise level – this is the so-called Lombard effect (Van Heusden, 1979). Laukkanen (1990) reported increased voice loudness when subjects' voices were masked by headphones while reading aloud. It was therefore considered to be of interest to test the effects of damped auditory feedback. Indeed, inverse results to the Lombard effect were found during damped auditory feedback: F0 and SPL decreased.

Lower F0 during amplification can be a by-product of a lower SPL (Sundberg, 1987; Titze, 1992). Compared to the effects of amplified auditory feedback F0 decreased relatively more than SPL in damped auditory feedback. Furthermore there was a negative correlation between the changes in F0 and those of SPL. Therefore F0 changes during damped feedback seem not to be a co-product of changes in SPL. It is tenable to assume that the causes are of both acoustical and physiological origin for the following reasons:
a) the dampening effect caused by the ear plugs was weaker at lower frequencies (below 500 Hz), so lower frequencies became more prominent;
b) the role of bone conduction increases during damping, causing higher pitched components to become weaker;
c) Since the higher components of the signal become weaker the sound is heard to be darker. Laukkanen (1994) demonstrated how people may adapt to the lower pitch they hear - especially if they like a lower pitched voice. Additionally, according to Lieberman (1967) people seem to have an inborn behavioural pattern of adapting their pitch according to the speaking pitch levels they hear in their environment.

6.1.1.2. Spectrum

During amplification statistically significant decreases were found both in F1-F0 level difference and in alpha ratio. However, when auditory feedback was damped no significant difference was found in any spectrum components. Decreased F1-F0 level difference suggests a relatively stronger fundamental. The relative strength of the fundamental in the source spectrum has been found to correlate positively with the glottal opening width (Gauffin and Sundberg, 1980). In turn alpha ratio measurements illustrate the average spectral slope. Gauffin and Sundberg (1980) pointed out that source spectrum slope correlated positively with the closing speed of the glottis. A pressed voice production with a strong vocal fold adduction is characterized by a relatively weak fundamental and decreased spectral slope and a strained, hyperfunctional voice. Production with a weak adduction is characterized by a relatively strong fundamental but increased spectral slope (Gauffin and Sundberg, 1980, 1989). Voice production with decreased F1-F0 level difference and alpha ratio may therefore suggest a turn towards a more hypofunctional direction during amplified auditory feedback. This is natural as SPL was lower with amplification, too.

6.1.2. Changes during amplification in class (II, IV,V)

To record a teacher's speech in working conditions may give a more reliable picture of the voice as it undergoes variations in vocal characteristics caused by physiological, emotional, educational and disciplinary factors during the day. In this study, the values obtained in the laboratory are within the limits of mean F0 reported in research literature (see Krook, 1988, for further review). However, the F0 values obtained in the field exceed those limits. This corresponds with the Rantala et al's (1998) laboratory and field studies, where the same discrepancy appeared. In field studies, because of the Lombard effect, talking to an audience against background noise and in a large room inevitably results in a rise in SPL and a consequent rise in F0 (or people raise F0 in order to raise SPL; for a review, see Vintturi, 2001, p.44-45).

6.1.2.1. Changes in fundamental frequency and sound pressure level

Results both from laboratory and field conditions have shown that amplified auditory feedback lowers SPL (Laukkanen, 1990; Sapienza, 1999; Chang – Yit et al., 1975). In this instance also, amplification significantly lowered both F0 and SPL in teachers' classroom speech. This was the case for all the five subjects in the present study. For females this lowering was about 10 Hz and 1 dB, for males about 11 Hz and 1 dB. The fact that Sapienza et al. (1999), in their study on 15-minutes lectures given by 10 teachers (6 males and 4 females) in an unoccupied classroom, found an average decrease of 2.4 dB during amplification could be due to differences in the level of amplification used in these studies. As no voice samples of the subjects' conversational voice were included in this study it is impossible to say if or how much rise there was in F0 and SPL in the classroom speech as compared to habitual speech.

Many findings, from both laboratory and field conditions, have shown a rise in F0 and /or SPL after vocal loading (e.g., Gelfer et al., 1991; Ohlson, 1988; Rantala et al., 1998; Novak et al., 1991, Pekkarinen et al., 1992; Stemple, 1995). Without amplification there were no significant differences in F0 and SPL between the first and the last lessons. This may indicate that vocal loading had caused a rise in F0 and SPL during the first lesson taught and that this state had continued throughout the entire working day, possibly because the first lesson had been so demanding that the teacher no longer had any resources for a normal, physiological increase of F0 and SPL. In contrast when using amplification, F0 and SPL were significantly higher in the last lessons. The reason may be due to causes listed below, factors which, generally speaking, can all be cited as explanations of why F0 and SPL rise during the working day, and are, therefore, postulated mechanisms in general.

a) *Adaptation to vocal loading:* Rantala and Vilkman (1999) found a greater increase during a working day in these parameters for those female teachers who had fewest voice complaints. It has therefore been hypothesized that a sufficient vocal loading-related rise in F0 and SPL shows the vocal organ's ability to adapt adequately to vocal loading (Rantala and Vilkman, 1999). According to background information the subjects of the present study experienced fewer vocal symptoms when amplification was used. This favours the hypothesis that a vocal loading-related increase in F0 and SPL is not, as such, a sign of vocal fatigue. This is also in line with Vintturi et al´s (2001) results on the effects of vocal warm-up (WU), where WU shifted the voice production in a hyperfunctional direction.

b) *Tissue viscosity:* The vocal fold vibration is set in motion according to the mobility and deformability of vocal fold mucosa, and the degree of irrigation by body fluids of this mucosa plays a key role in how easily this vibration is achieved (Titze, 1994). If the vocal fold mucosa dried during the working-day, it could lead to a need to produce voice with greater effort (due to stiffer mucosa) and, thus, increased F0 and SPL. (Verdolini – Marston et al., 1990; Sihvo, 1997). Scherer et al. (1987), found that abusive voice production leads to swollen vocal folds anteriorly with edema of both vocal folds and perturbation in jitter and shimmer. However if the mucosa swelled (i.e., contained more water), it could possibly lead to decreased viscosity (i.e., closer to the lesser viscosity of water). Thus, the effect of vocal fold oedema would possibly not be an increase in effort; moreover, a swollen vocal fold vibrates with lower F0.

c) *Circadian rhythm:* In their investigation on F0 and SPL in female and male teachers' voices Artkoski et al. (2002) showed that there seems to be a tendency for F0 to rise in the afternoon even when the voice has not been used. This may be due to changes in psycho-physiological activity related to the circadian rhythm of the human body (Bouhys et al., 1990).

d) *Emotional causes*: As F0, SPL and glottal waveform reflect the speaker's mood (Laukkanen et al., 1996), changes in voice may be expected in prolonged voice use not least in the voices of teachers, who have to use their voices both as educational and disciplinary tools.

Changes in F0 and SPL can be seen amongst individual subjects in samples taken from the very beginning, middle and the ending of the lessons (IV). What was characteristic of the use of amplification was a tendency for there to be a rise in F0 in the end of the last lessons in the working day (IV). Effects of situational factors (type of classroom communication, emotional and other psycho-physiological states of the teacher, etc.) cannot be excluded. It is therefore possible that as the day wore on students may have become less attentive, especially at the end of the school day. This may have lead to increased use of the voice as a disciplinary tool by the teacher, or teachers may have become used to the amplification and tended to return to their former vocal habits when class communication worsened. However, on the basis of listening analysis on the content of the classroom speech there did not seem to be much difference between the last lessons with/without amplification in this respect.

When not using amplification these tendencies towards higher F0 at the end of the last lesson were not as characteristic as when amplification was used. Indeed, with three of the subjects the opposite happened: the F0 became lower at the end of the last lesson. This fall in F0 could be interpreted as a sign of vocal fatigue after prolonged voice use in classroom noise.

6.1.2.2. Phonation time

Amplification did not significantly change phonation time. This confirms the questionnaire answers (III) where only 4% of the 33 teachers stated that they talked more using amplification. On the other hand, the verbal style of the teachers could have differed when using amplification. With perceptual analysis it was noticeable that teachers spent more time in the exposition of their teaching material when amplification was used and less time repeating themselves and/or establishing discipline, which was frequently done when not using amplification.

6.1.2.3. Spectrum

With amplification for both first and last lessons there was an increase in spectral slope for all measured ranges (1-2 kHz, 2-3 kHz, 3-4 kHz 4-5 kHz and 5-10 kHz) compared to unamplified conditions. The differences between amplified and unamplified lessons were considerably greater for the first lesson than for the last lesson. For the first lesson amplification increased the slope on the average 3.5 dB for 1-2 kHz and 1.7 dB for 2-3 kHz. For the last lesson this difference was on the average only 0.3 dB for 1-2 kHz and 0.1 dB for 2-3 kHz. This suggests that in the first lesson with amplification the subjects used softer voices with lower vocal effort, i.e. decreased force in the closing of the vocal folds, diminished respiratory activity and less speed in the glottal closing. This is known to induce less fatigue. While using amplification there was however a significant rise in spectrum in the last lessons. It may be hypothesized that increased activity in the laryngeal muscles and/or decreased viscosity in the vocal fold tissue had taken place. A change towards a less steep spectral slope can be seen as one of the normal vocal-loading related changes in the voice. Rantala and Vilkman (1999) found that energy changes in higher spectral components increased during a working day for teachers with fewer vocal complaints. However, those changes, typical of adaptation, may also be seen as reflecting hyperfunction, i.e. too strong adduction and subglottal pressure leading to fatigue changes.

When the subjects were not using amplification few changes were seen in the spectrum during the working day. As the subjects reported they suffered from multiple vocal symptoms, the results are in line with Rantala et al's study (1998) which found negligible changes in spectrum over a working day for teachers with many vocal symptoms. Small changes in the spectrum in classroom speech under ordinary conditions could indicate that the subjects already started to use strained loud voices in the first lessons. It is well known that higher spectral harmonics gain more in amplitude than the lower harmonics when SPL is raised (e.g., Sundberg, 1987; Löfqvist, 1986; Gramming, 1991). Additionally, as the spectrum slope is positively related to the speed of the glottal closing, it may be said that a less steep slope is demonstrating stronger overtones. High speed in the closure means harder collision, which may be harmful to the vocal folds (Scherer et al., 1987).

6.1.2.4. Work-related changes in spectrum according to gender

Study results have shown that female voices tend to change in a hyperfunctional direction during vocal loading (Novak et al., 1991; Rantala et al., 1998; Löfqvist, 1986; Ohlson, 1988; Lauri et al., 1997**).** In contrast, the spectra of male voices have shown fewer changes during vocal loading (Lauri et al., 1997) or even an opposite tendency, becoming hypofuctional during vocal loading (Novak et al., 1991).

In Studies II, III, IV and V there were 3 female voices and 2 male voices. The spectra of the female voices in the last lesson without amplification were well in line with earlier studies, which showed a less steep spectrum after vocal loading (Rantala et al., 1998; Novak et al., 1991). Additionally, these changes in spectrum for female voices during vocal loading are in keeping with studies on a) changes in time-based glottal flow waveform parameters (Lauri et al., 1997) showing increased SQ (speed quotient) and decreased ClQ (closing quotient), b) studies on amplitude domain changes showing increased d_{peak}, increased f_{AC} (Vilkman et al., 1999), c) increased F0, increased subglottal pressure and increased SPL after vocal loading (Kitzing, 1979; Gelfer et al., 1991; Vilkman et al., 1999; Rantala and Vilkman, 1999). In fact these same changes (increased F0, increased subglottal pressure and increased SPL) were present in males in Vilkman et al's study (2002). All above mentioned parameter changes reflect a shift towards more effortful or hyperfunctional voice production.

In the present study, one of the males in his last lesson of the day without amplification equipment showed a tendency to become hypophonic, marked by a steeper slope in the spectrum. In this subject, during the last lesson, a still greater increase was seen in the slope while using amplification. This teacher had been teaching for 8 hours this day, according to schedule, with short breaks. In the last lesson taught without amplification he was clearing his throat, hesitating and repeating himself – the implication being that he was becoming fatigued. This was not the case when he was using amplification in the last lesson, which could point to less fatigue due to use of the amplifier.

In the case of the other, older male who reported suffering from more severe voice problems, the spectrum showed the same trend as the female voices, i.e. it became more hyperfunctional during vocal loading. This raises the question as to whether the different results obtained for males and females in vocal loading tests are due to gender or to individual differences in vocal endurance. There is individual variation in all vocal characteristics so what may be related to vocal fatigue in one subject may not be related to it in another. Thus, hypofunctional voice may be a sign of fatigue - a kind of a "giving up" reaction. Alternatively, hyperfunctional quality may be due to an attempt to overcome changes related to fatigue or be simply a sign of successful adaptation to loading.

From a physiological point of view the female voice may be more vulnerable to vocal loading due to physiological causes, such as smaller and weaker structure of the vocal mechanism (Bridger and Epstein, 1983; Fritzell, 1996; Herrington-Hall et al., 1988; Lauri et al., 1997; Vilkman, 2000) The fact that female vocal folds vibrate roughly twice as often per unit time (Vilkman, 2000) as those of male may be a crucial factor in this respect. According to Lauri et al. (1997), females tend to increase glottal adductory force as a response to vocal loading. Jiang and Titze (1994) pointed out that impact stress (the force with which the vocal folds collide) increases as a function of F0 and SPL and adduction. However, the results of this preliminary study should be taken with caution as the number of the subjects limits the possibilities of drawing conclusions. Whatever may be the case, the results call for further investigation into possible differences in vocal behaviour according to gender. It is tenable to hypothesize that female vocal folds may behave differently in loading tests because of the differences in laryngeal structure.

6.2. LISTENING EVALUATION (V)

Results of the listening evaluation of the voice samples by the author suggest that when teachers used amplification, they went into greater detail, repeated themselves less, and used less of their time in establishing discipline.

According to the voice trainers' listening evaluation, voice quality was not found to be good in any of the samples, either in those taken under amplification or those in non-amplified conditions. All the teachers had long teaching experience and according to the results of research questionnaires their profession is considered to be at high risk for voice problems, so the results from listening evaluation should not be a surprise. However, the voices were perceived as less strained in amplified conditions, which is in accordance with the lower F0, SPL and steeper spectral slope. This indicates softer adduction. Additionally, the perceived strainedness increased during the working day somewhat more when amplification was used, possibly due to a "lower baseline level", i.e. less strainedness in the first lesson due to amplification. This was also in accordance with the acoustical measurements that showed a greater decrease in spectral tilt compared to unamplified conditions. As strainedness correlated positively with a decreased spectral tilt so did asthenity and breathiness correlate with increased spectral tilt. This is in line with earlier findings (Hammarberg, 1986; Kitzing, 1986). As the present material consisted of relatively loud classroom speech it was not expected to find vocal fry which exists in quite low-pitched and relatively soft speech. Roughness, though to a relatively limited extent, was found more often in voice samples taken in non-amplified conditions. Roughness is related to irregular vocal fold vibration, and that in turn has been found to increase when there is hyperfunctionality in the voice (Beckett, 1969), or when the vocal fold condition is not good - e.g., due to vocal fatigue. The fact that the voice was found to be less asthenic in amplified conditions may be related to lower F0 and therefore a lower load. Additionally the voice was perceived as more relaxed when using amplification, which may have given the voice a more natural timbre

The spectral slope decreased clearly during the day with amplification as stated above. However, for the listeners the voices sounded only slightly less asthenic in the samples from the last lessons. This discrepancy between clear change in LTAS and less clear change in perception may be due to the fact that the strongest parts of the signal mark the form of the LTAS but these strongest parts may not necessarily be those most apparent to the listener.

The measured mean difference in average F0 without and with amplification was 0.66 semitones expressed on a musical scale. That may be the reason why no differences were found in perceived pitch although there were differences in F0. A difference that is less than 1 semitone may be too slight to be perceived by any but those with perfect pitch. Additionally, as the samples were in random order it was difficult if not impossible to detect pitch differences. Perceptual differences in average speaking pitch cannot be expected to be as accurate as acoustically measured average F0, especially in a speech sample in which pitch varies all the time.

Vocal fatigue is a difficult quality to deal with because it is identified by subjective interpretations of varied characteristics of the voice. This may be the explanation why no significant difference was found in perceived vocal fatigue in samples recorded in the two conditions (with and without amplification), and why inter-observer consistency (between listening evaluations by two listeners) was low for perceived vocal fatigue. The cloudiness and roughness correlated, however, with the perception of fatigue for both listeners, which is in line with earlier study results where those vocal characteristics have been found to coincide with perceived fatigue (Laukkanen et al., 2001). As these voice samples were from loud classroom speech which varied in pitch it is plausible to assume that some characteristics were unlikely to exist in the samples, e.g., vocal fry, where there was low intra-observer consistency found. Likewise low inter-observer consistency was found in asthenity, breathiness and roughness.

6.3. TEACHERS' AND STUDENTS' OPINIONS ON AMPLIFICATION IN TEACHING (III)

6.3.1. The teachers

Only two of the 33 teachers in Study III were familiar with the use of amplification before the test. It is therefore possible that general satisfaction with the use of amplification could stem from the effect that attention was paid to the amplified feedback and, therefore, more attention focussed on the teachers' own voice use. The result may have been that the teachers used softer voices with amplification, resulting in softer adduction of the vocal folds. Indeed that is in accordance with lowered F0, SPL and increased spectral tilt.

While using amplification the teachers reported less fatigue in the vocal mechanism, especially in the throat, which may be partly related to decreased levels of F0 and SPL. Additionally, the majority of the subjects reported better voice production and less fatigue in the body. It is possible to conclude that stress had become less, especially when it is remembered that the teachers found that students paid more attention, there was less classroom chatter, and they felt less need for repetition. Interestingly, all of the subjects admitted to discomfort in the voice mechanism when teaching without amplification. While using amplification, only 14 (42%) of the subjects answered this question which may suggest that no discomfort was felt.

The results suggest also that vocal load at work has a significant effect on the general well-being of the voice professional.

6.3.2. The students

Leavitt and Flexer (1991) used Rapid Speech Transmission Index (RASTI) to estimate speech perception in a classroom. According to their results only 55% of the sound energy is available to the listeners in the centre of the back row of seats in a classroom. When Crandell and Bess (1986) examined the speech recognition of young children (5 to 7 years old) they found that there was a systematic decrease in speech-recognition ability as speaker-listener distance increased. Those experiments were carried out in what they called "typical" classroom environment (signal to noise ratio = +6dB; RT =0.45 s.).

It is to be regretted that it was not possible to carry out acoustical measurements of the classrooms in this present study because no acoustic devices were available in Akureyri. In the present study we therefore do not know the acoustical conditions in the classrooms. The size of the classrooms varied considerably (from 40m^2 in a junior college classroom up to a 158 m^2 auditorium in the university and a gymnastic hall of 175 m^2). The distance between the teacher and the pupils therefore varied considerably. In their free comments on the teacher's use of amplification, three quarters of the students commented that they heard better. This was also the case for over 95% of the youngest students (6-9 years old). In addition, the students stated that the use of an amplification system facilitated listening and improved concentration. Surprisingly few students found the amplification annoying in spite of simple and inexpensive equipment. It may be because: a) this generation is so used to amplified sound that it is not so sensitive to its flaws and disadvantages, or b) hearing problems among young people are increasing (Ray Hull, personal contact 2001). Listening abilities could therefore be poorer than one would expect. For some students the pleasure of being able to hear better may cause them to overlook discomfort. A comparison with other studies concerning this aspect of the research is difficult, as general use of amplification for non-handicapped children in classrooms is still not common practice. Research on the effects of amplification on behaviour or learning difficulties in children has shown positive results and, additionally, positive effects on the voice of the teacher (Palmer, 1998; Allen and Patton, 1990; Gilman and Danzer, 1989).

As far as vocal health is concerned, the benefits reported by teachers and pupils in this study are much in line with results from other studies – 1) for teachers: reduced voice fatigue, less need for repetition, improved student attention, improved behaviour, fewer distractions, diminished discipline problems 2) for students: easier to hear the teacher, improved attention, class noise diminished, teacher heard without the need for straining (Sarff, 1981; Berg et al., 1989; Gilman and Danzer, 1989; Allen and Patton, 1990; Rosenberg, et al., 1994; Palmer, 1998; Flexer, Millin and Brown, 1990; Lehman and Gratiot, 1983).

6.3.3. Problems related to amplification

Teachers and students agreed that the main disadvantages related to amplification stemmed from technical problems and the teachers' lack of knowledge about the proper use of the equipment; they cited too much amplification, acoustic feedback and problems experienced in setting up the equipment. This is very much in line with what Flexer et al. (1995) indicated might be the main disadvantages with amplification in classrooms, when they cited too much amplification, inappropriate amplification systems in the classroom and insufficient technical knowledge in the teacher. Flexer et al. (1995) emphasised a) the necessity for teachers to learn how to use the equipment; b) an appropriate amplification system for the room; c) appropriate number and positioning of loudspeakers; d) user-friendly microphones placed at the correct distance from the mouth of the speaker (6 inches is recommended) and e) someone with adequate expertise available in the school district to install and maintain the equipment. In Icelandic schools where amplification is available, experience has shown that the amplification system has to be simple to use and there is a need for a suitable expert within the school itself. If the teachers are not taught to use the equipment, or if some problem arises with which they cannot cope, they stop using it. As communication between teacher and student begins as soon as the teacher enters the classroom and teachers cannot waste time tuning a complicated system, it is important that the equipment is as simple to use as possible.

As amplification in ordinary classrooms has been rare up to now, it is possible that some technical problems may arise with more widespread use. Boothroyd (1992) pointed out that if too few bands are made available there may be a limit on the number of sound field units which can be installed in the same building, while too many bands per carrier frequency may increase interference and unfavourable S/N ratio within the equipment itself.

6.3.4. Improving he teachers' vocal ergonomics

It is plausible to assume that the main cause of the voice problems which are known to afflict teachers may be rooted in general lack of knowledge about voice production and the capacity of the voice. This widespread ignorance has meant that not enough attention has been given to "vocoergonomic" considerations, such as a) training teachers in the care of the voice and b) ensuring that classrooms are acoustically adequate for their purpose, e.g., by limiting reverberation time and equipping larger rooms with amplification equipment. Up to the present, there has been a gross lack of understanding of the issues by those concerned, amongst both teachers and the authorities. Cooper (1970) and Comins (1992) pointed out that teachers seem to accept that the voice will inevitably break and they consider voice loss as an "occupational hazard". Vilkman (1999) states that "apparently one of the main underlying problems is the shortage of knowledge concerning the environmental and ergonomic aspects of voice disorders as an occupational health problem". Historically, knowledge about occupational risks and ways in which working conditions can be improved has been growing steadily. This knowledge is leading towards the realisation that better working conditions produce better results and a longer effective working life among employees, and it has, little by little, had a positive effect on the people's understanding of the situation. Undoubtedly, the great number of teachers who suffer from voice disorders demonstrates the vital need for improved vocoergonomics in their working environment. Efforts are therefore being made to bring the voice under the scope of safety-at-work legislation and so make the protection of the voice a responsibility of employers.

6.3.4.1. Voice training

The introduction of amplification systems will not eliminate the need for teachers to have adequate information about the voice, voice training, and knowledge about how to protect the voice. The introduction of voice training and courses in voice care and voice use have long ago proved that well trained voices have greater SPL and greater F0 range in speech (Awan, 1993; Kitzing and Åkerlund, 1993), show less manifestation of vocal fatigue (Novak et al., 1991; Gelfer et al., 1991), suffer from fewer vocal symptoms and so the voice tends to be better controlled (Comins, 1992; Ohlson, 1993; Martin, 1994; Roy et al., 2001), and the employees take less sick leave (Martin, 1994).

6.3.4.2. Improved acoustical conditions

It is well known that good acoustics are crucial both for speech discrimination and voice use. It is therefore of interest that Pekkarinen (1988, p84) points out that "little or no data are yet available on such acoustic improvements of rooms which have been controlled with speech discrimination tests". It is clear that there is a need for such research to be carried out and for the results to be widely promulgated.

It has been shown that the reverberation time is too high in many classrooms (e.g., Crandell and Smaldino, 1994). Asha (1995) stated that a level of 0.4 s is to be recommended, especially for young listeners. Pekkarinen (1998) demonstrated that speech discrimination can be improved by reducing reverberation time in classrooms, for example by increasing the signal to noise ratio by the use of sound-absorbing panels. According to Pekkarinen (1988), sound-absorbing panels have been found particularly effective when applied so as to cover the ceilings and two of the walls of square or rectangular rooms. She also pointed out, however, that there is a risk of installing too much sound-absorbing material, so that the speech sounds cannot reach the learners because of lack of reflection.

6.3.4.3. Damped auditory feedback

Background noise in the classroom contributes to more strenuous voice use. Because of the Lombard effect (Van Heusden, 1979), teachers unconsciously use a louder voice in such conditions. The results from this study indicate lower F0 and SPL if auditory feedback is damped. Nevertheless, this may be unfavourable on the communicative point of view. Interestingly, F0 decreases relatively more than SPL which should be beneficial for the students as the loudness of the teacher's voice is probably sustained better due to less vibration of vocal fold mucosa. Moreover, decreased vocal effort on the part of the teacher may be beneficial for the student in the long term, as the teacher experiences fewer vocal problems.

6.3.4.4. Amplification

Many classrooms are large and noisy. It has been documented that the noise level in occupied classrooms is, on average, 55 – 77 dB(A) (e.g., Markides, 1986; Airey, 1998; Berg, 1993). It has also been estimated that the teacher's speech output varies between 58-79 dB in classroom teaching (Pekkarinen and Viljanen, 1990). To reach the goal of 15-20 dB in S/N which is recommended by ASHA (1995) for young listeners and disabled students, the SPL in teachers' voices has therefore to reach a level of 70 to 97 dB. Considering the louder end of the range, is it really possible to force any voice into such strenuous use day after day, even when the voice has been trained effectively?

Voice training is essential, but as Vilkman (2001) says: " it can be suspected that even in the field of "vocoergonomics" i.e., the ergonomics of voice use, the conclusion will be that training of individuals is important but not sufficient to control the health hazards at work with an acceptable cost/effect ratio". Otting et al. (1992) looked at the possibilities of training teachers to increase their vocal capacity in the classroom. He found that it was possible to train teachers to increase their capacities, but that continuous training was necessary if teachers were to retain their increased capacity. He concluded that classroom amplification is the most effective way to increase teachers' voice levels over and above their habitual speech levels. Roy et al's (2001) conclusions were that the beneficial results of amplification went further than giving the subjects vocal hygiene instruction. As Vilkman (2001) states: "Use of adequate voice amplification equipment would be the quickest and cheapest way to reduce vocal load in many overloading conditions".

Verdolini and Ramig (2001) pointed out that teachers' voice problems cost the United States a considerable amount of money each year. In school session 2001-2002 in Iceland, the cost of providing amplification equipment (Fohhn Direct Media amplifier and Shure cordless system) in one classroom was approximately equivalent to employing a supply teacher for eight days to cover for an absentee.

However, it must not be concluded that the introduction of amplification is inevitably advantageous. In some acoustic conditions, such as when there is a long reverberation time in the classroom, amplification may produce echo. In these circumstances there may be more disadvantages than advantages in the use of amplification.

According to the results of this preliminary study an effective amplification system is an important additional element in the battle for better vocal health for teachers, and assists learners to hear better what is being taught. The implications of these findings are that whether teachers work in old or newly-built classrooms each of them should have access to an amplification system, either as part of the standard classroom fittings or provided as portable equipment, free to be deployed from room to room.

7. CONCLUSIONS

In this study the hypothesis was posed that not only would the teacher's voice be protected by amplified auditory feedback, but also that the learners would be able to hear with greater clarity, and with fewer interruptions, what the teacher was saying. This study therefore set out to investigate these twin assumptions, and the conclusions have been reached. *Quantum satis* the teachers and the pupils agreed that use of an amplification system in the classroom is "vocoergonomic", i.e. the teacher's voice is protected and at the same time the learners can hear the teacher's voice more clearly.

The results showed that both damped and amplified auditory feedback lowered F0 and SPL (I, II, IV) and spectral slope became steeper (I, V). They also highlighted possible gender-related differences in the effects of vocal loading which warrant further study (V). Amplification may have contributed to vocal changes that indicate normal adaptation to loading. This could be seen in a larger increase in SPL and larger decrease in spectrum slope during the working-day when amplification was used. However, those changes, typical of adaptation, may also reflect hyperfunction in a negative sense; too strong adduction and subglottal pressure leading to fatigue changes. Nevertheless more hyperfunctional voice production could be expected in the end of a working day when teachers are without use of amplification than when using amplification. Voices were evaluated as less strained and better in quality when amplification was used (V). With amplification teachers found voice production easier and vocal symptoms were reduced, as was fatigue in the vocal mechanism and in the body (III). The students found that the teacher's voice could be heard more clearly, difficulties in hearing the teacher were reduced, concentration became easier and students paid more attention to the lessons (III). Both teachers and students agreed that amplification contributed to decreasing classroom chatter (III). Likewise, teachers and students agreed on a few disadvantages, mainly technical problems and lack of knowledge on how to use the equipment.

It may be concluded that the use of amplification systems should become widespread in the future and new classrooms should automatically be provided with amplification systems.

Further research is required to identify the kinds of amplification equipment most suited to the acoustics of rooms of different sizes and shapes, and those which are most user-friendly for teachers. Technological development in this area is taking place rapidly and unit costs of the equipment are decreasing steadily; the establishment of key design principles by research would make it possible for appropriate technology to be developed and available at low cost for schools and individual teachers.

Research is required to find out whether the use of amplification has implications for the nature of classroom communication and teaching styles, and for the design of educational programmes.

From the point of view of the practising teacher, there is much to be learned about the influence of the long-term use of amplification on vocal parameters and vocal health. Gender differences in vocal changes also warrant further study.

8. REFERENCES

1) Airey S. A survey of acoustical standards in UK classrooms and their effect on students and teachers. *Proceedings of the Institute of Acoustics*, 1998; Vol 20: part 4: 14 - 21.
2) Åkerlund L, Gramming P. Average loudness level, mean fundamental frequency and subglottal pressure; comparison between female singers and nonsingers. *Journal of Voice*, 1994; 8: 263-270.
3) Alku P, Vilkman E. A comparison of glottal voice source quantification parameters in breathy, normal and pressed phonation of female and male speakers. *Folia Phoniatrica et Logopaedica*, 1996; 48: 240-254.
4) Alku P, Vilkman E, Laukkanen A-M. Parameterization of the voice source by combining spectral decay and amplitude features of the glottal flow. *Journal of Speech, Language and Hearing Research*, 1998; Oct: 990 –1002.
5) Alku P, Vintturi J, Vilkman E. On the linearity of the relationship between the sound pressure level and the negative peak amplitude of the differentiated glottal flow in vowel production. *Speech Communication*, 1999; 269-281.
6) Allen L. Promoting the usefulness of classroom amplification. *Educational Audiology Monograph*, 1993; 3: 32-34.
7) American Speech-Language-Hearing Association. Position statement and guidelines for acoustics in educational settings. *ASHA*, 1995 (March): 37 (supplement 14): 15-19.
8) Andrews, M. L. *Manual of Voice Treatment*. San Diego: Singular Publishing Group, Inc., 1995.
9) Aronson, A. E. *Clinical Voice Disorders*. New York: Thieme Stratton, 1985 (2nd Ed.).
10) Artkoski M, Tommila J, Laukkanen A-M. Changes in voice during a day in normal voices without vocal loading. *Logopedics Phoniatrics Vocology.* 2002; 27: 3: 118-123.
11) Awan SN. Superimposition of speaking voice characteristics and phonetograms in untrained and trained vocal groups. *Journal of Voice,* 1993; 7: 1: 30-37.
12) Beckett RL. Pitch perturbation as a function of subjective vocal constriction.

Folia Phoniatrica. 1969; 21: 416-425.

13) Berg FS. *Acoustics and Sound Systems in Schools*. San Diego: Singular publishing group Inc., 1993.

14) Berg F, Bateman R, Viehweg S. Sound field FM amplification in junior high school classrooms. *Paper presented at the American Speech-Language-Hearing Association Convention* St. Louis MO, 1989.

15) Blood GV. Judging personality and appearance from voice disorders. *Journal of Communication Disorders*, 1979; 12: 63-68.

16) Boone D. *Is Your Voice Telling on You?* San Diego: Singular publishing group Inc., 1991.

17) Boothroyd A. The FM wireless link: An invisible microphone cable. In Ross M. (Ed.): *FM Auditory Training System: Characteristics, Selection and Use*. Timonium; MD: York Press, 1992: 1-19.

18) Borden GJ, Harris KS, (Eds.). *Speech Science Primer: Physiology, Acoustics and Perceptions of Speech*. Baltimore: Williams and Wilkins, 1984.

19) Bouhuys AL, Schutte HK, Beersma DGM, Nieboer GLJ. Relations between depressed mood and vocal parameters before, during and after sleep deprivation: a circadian rhythm study. *Journal of Affective Disorders,* 1990; 19: 249–258.

20) Bridger MW, Epstein R. Functional Voice Disorders: A review of 109 patients. *Journal of Laryngology and Otology,* 1983; 97: 1145-1148.

21) Brodnitz F. Vocal rehabilitation. *American Academy of Ophthalmology and Oto-Laryngology*, 1971.

22) Buekers R, Bierens E, Kingma H, Marres EHMA. Vocal load as measured by the voice accumulator. *Folia Phoniatrica. Logopedica.,* 1995; 47: 252–261.

23) Ceuppens P. Voice problems in teachers. *Antwerp: Katholieke Vlaamse Hogeschool*, 1995.

24) Chang-Yit R, Herbert L, Pick JR, Siegel GM. Reliability of sidetone amplification effect in voice intensity. *Journal of Communication Disorders,* 1975; 8: 317-324.

25) Childers DG, Lee CK. Vocal quality factors. Analysis, synthesis and perception. *Journal of the Acoustical Society of America*, 1991; 90 : 2394-2410.

26) Coleman RF, Mabis JH, Hinson J. Fundamental frequency-sound pressure level profiles of adult male and female voices. *Journal of Speech and Hearing Research*, 1977; 20: 197-204.

27) Coleman RF and Markham IW. Normal variations in habitual pitch. *Journal of Voice,* 1991; 2: 5: 173-177.

28) Coleman RF. Sources of variation in phonetograms. *Journal of Voice,* 1993; 7: 1: 1–14.

29) Colton RH; Casper JK. *Understanding Voice Problems.* Baltimore, Maryland: Williams and Wilkins, 1990.

30) Comins, R. Voice Forum: Voice in the Curriculum. *Voice*, 1992; 1: 67-73.

31) Comins R. Survey of teachers in voice caseloads. In: Comins R (Ed.) *Voice and the Teacher: An Information Pack*. Kenilworth: Voice care network UK, 1995.

32) Comins J. A comparison of smokers' and non-smokers' voices in two age groups using Fx and carbon monoxide data. In: Mac Curtain F. and Kersner M. (Eds.) *European Voice Technology Seminar. Selected papers*. London: National Hospitals College of Speech Sciences, 1990: 67-72.

33) Cooper M. Vocal Suicide in Teachers. *Peabody Journal of Education*, 1970; May: 334-337.

34) Crandell C and Bess F. Speech recognition of children in a "typical" classroom setting. *ASHA,* 1986; 29: 87.

35) Crandell C. Classroom acoustics of normal hearing children; Implications for rehabilitation. *Educational Audiology Monograph*, 1991; 2: 18-38.

36) Crandell C. A comparison of commercially–available frequency modulation sound field amplification systems. *Educational Audiology Monograph*, 1993; 3: 15-20.

37) Crandell C. The effects of noise on the speech perception of non-native English children. Submitted to *Language, Speech and Hearing Services in the Schools,* 1994.

38) Crandell C, Smaldino J. An update of classroom acoustics for children with hearing impairment. *The Volta Review*, 1994; 96: 291-306.

39) Crandell C, Smaldino J, Flexer C. Speech perception in specific population. In: Crandell C, Smaldino J, Flexer C (Eds.), *Sound-Field FM Amplification:*

Theory and Practical Applications. San Diego: Singular publishing group Inc., 1995: 49-65.

40) Crandell C, Smaldino J (a). Classroom acoustics. In Roeser RJ and Downs MP (Eds.): *Auditory Disorders in School Children* (3rd Ed.). New York: Thieme Medical Publishers Inc., 1995: 219-234.

41) Crandell C. and Smaldino J. (b) Speech perception in the classroom. In: Crandell C, Smaldino J, Flexer C (Eds.). *Sound Field FM Amplification, Theory and Practical Applications*. San Diego: Singular publishing group Inc, 1995: 29-48.

42) Dejonckere PH. Gender differences in the prevalence of occupational voice disorders. In: Dejonckere PH (Ed.). *Occupational Voice: Care and Cure*. Hague: Kugler Publications, 2001: 11-20.

43) Dobie R, Berlin C. Influence of otitis media on hearing and development. *Annals of Otology, Rhinology and Laryngology,* 1979; 88: 48-53.

44) Elliot L. Effects of noise on perception of speech by children and certain handicapped individuals. *Sound and Vibration*, 1982: December: 9-14.

45) Fant G. *Acoustic Theory of Speech Production*. The Hague: Mouton, 1960.

46) Fawcus M. *Voice Disorders and their Management*. London: Chapman & Hall, 1991.

47) Finitzo – Hieber T, Tillman T. Room acoustics effects on monosyllabic word discrimination ability for normal and hearing-impaired children. *Journal of Speech and Hearing Research*, 1978; 21: 440-458.

48) Finitzo – Hieber T. Classroom Acoustics. In Roeser R, Downs M (Eds.). *Auditory Disorders in School Children*. New York: Thieme – Stratton, 1988; 2nd ed.: 221-233.

49) Flexer C, Millin J, Brown L. Children with developmental disabilities: The effect of sound field amplification on word identification. *Language, Speech and Hearing Services in Schools,* 1990; 21: 177-182.

50) Flexer C, Crandell C, Smaldino F. Considerations and strategies for amplifying the classrooms. In: Crandell C, Smaldino J, Flexer C (Eds.). *Sound-Field FM Amplification: Theory and Practical Applications*. San Diego: Singular publishing group Inc., 1995; 125-148.

51) Florida department of Education. Improving classroom acoustics; *Inverse Training Manual*, Tallahassee, FL, 1994.

52) Forchammer E. *Stemmens Funktioner og Fejlfunktioner* (in Danish). Copenhagen: Egil Forchammer og Munksgaard, 1974.

53) Freidl W, Friedrich G, Egger J & Fitzek T. Psycho-social Aspects of Functional Dysphonia. *Scandinavian Journal of Logopedics & Phoniatrics*, 1993; 18: 4: 115-119.

54) Fritzell B. Voice disorders and occupations. *Logopedics. Phoniatrics Vocology,* 1996; 21: 7-12.

55) Frøkjær – Jensen B, Prytz S. Registration of voice quality. *Brül and Kjær. Technical review,* 1976; 3: 3–17.

56) Garrett KL, Healey EC. Acoustic analysis of fluctuations in the voices of normal adult speakers across three times of day. *Journal of the Acoustical Society of America.,* 1987; 82: 1: 50-62

57) Gauffin J, Sundberg J. Data on the glottal voice source behavior in vowel production. *STL-QPSR,* 1980; 2-3: 61-70.

58) Gauffin J, and Sundberg J. Spectral correlates of glottal voice source waveform characteristics. *Journal of Speech and Hearing Research.,* 1989; 32: 556-565.

59) Gelfand S, Silman S. Effects of small room reverberation upon the recognition of some consonant features. *Journal of the Acoustical Society of America*, 1979; 66: 1: 22-29.

60) Gelfer MP, Andrews ML, Schmidt CP. Effects of prolonged loud reading on selected measures of vocal function in trained and untrained singers. *Journal of Voice*, 1991: 5: 158-167.

61) Gilman L, Danzer V. Use of FM sound field amplification in regular classrooms. Paper presented at the *American Speech–Language-Hearing Association Convention,* St. Louis MO, 1989.

62) Goldman SL, Hargrave J, Holmberg E, Gress C. Stress, anxiety, somatic complaints and voice use in women with vocal nodules: Preliminary findings. *American Journal of Speech–Language Pathology*, 1996; 5: 44-54.

63) Gotaas C, Starr CD. Vocal fatigue among teachers. *Folia Phoniatrica et Logopaedica,* 1993; 45: 120-129.

64) Gramming P. Non-organic dysphonia: phonetograms for pathological voices before and after therapy. *Scandinavian Journal of Logopedics and Phoniatrics,* 1988; 13: 1: 3-16.

65) Gramming P. Vocal loudness and frequency capabilities of the voice. *Journal of Voice,* 1991; 5: 2: 144-157.

66) Gray SD, Titze I, Lusk RP. Electron Microscopy of hyperphonated canine vocal cords. *Journal of Voice*, 1987; 1: 1: 109-115.

67) Gray, SD. Basement Membrane Zone Injury in Vocal Nodules. In: Gauffin & Hammarberg (Eds.). *Vocal Fold Physiology, Acoustics, Perceptual and Physiological Aspects of Voice Mechanism*. San Diego: Singular Publishing Group Inc.,1991: 21-27.

68) Green K, Pasternak B, Shore B. Effects of aircraft noise on reading ability of school age children. *Archives of Environmental Health*, 1982; 37: 24–31.

69) Greene M, Mathieson L. *The Voice and its Disorders*. London: Whurr, 1991.

70) Hammarberg B. Perceptual and acoustic analysis of dysphonia. *Doctoral Dissertation. Karolinska Institutet*, Stockholm, 1986.

71) Hammarberg B. Pathological voice qualities perceptual and acoustic characteristics of a set of Swedish “reference voices”. *Phoniatric and Logopedic Progress Report*. Stockholm: Karolinska Institutet, Huddinge Hospital., 1992; 8: 15-22.

72) Harris C. *Handbook of Noise Control*. New York: McGraw – Hill, 1979.

73) Harris T, Lieberman J., Voice Forum: The cricothyroid mechanism, its relation to vocal fatigue and vocal dysfunction. *Voice*, 1993; 2: 89-96.

74) Hay B, Comins R. Voice Forum: A pilot study of classroom noise levels and teachers' reactions. *Voice*, 1995: 4: 127-134.

75) Heidel SE, Torgerson JK. Vocal problems among aerobic instructors and aerobic participants. *Journal of Communication Disorders,* 1993; 26: 179-191.

76) Herrington-Hall B, Lee L, Stemple J, Niemi K, McHone MM. Description of laryngeal pathologies by age sex and occupation in a treatment-seeking sample. *Journal of Speech and Hearing Disorders,* 1988; 53: 57-64.

77) Hétu R, Truchon-Gagnon C, Bilodeau SA. Problems of noise in school settings: A review of literature and the results of an exploratory study. *Speech-Language Pathology and Audiology*. 1990; 14: 31-39.

78) Hirano M. Phonosurgery. Basic and clinical investigations. *Otologia* (Fukuoa), 1975; 21: 239-440.

79) Hirano M. *Clinical Examination of Voice. Disorders of Human Communication 5. Ed.* by Arnold GE, Wincle F, Wyke BD. Wien: Springer-Verlag, 1981.

80) Hirano M. The structure of the vocal folds. In: Stevens K, Hirano M (Eds.). *Vocal Fold Physiology*. Tokyo: University of Tokyo, 1983; 33-43.

81) Hirano M, Tanaka S, Fujita M, Terasawa R. Fundamental frequency and sound pressure level of phonation in pathological states. *Journal of Voice*, 1991; 5: 2: 120-127.

82) Hiss SG, Treole K, Stuart A. Effect of age, gender, and repeated measures on intraoral air pressure in normal adults. *Journal of Voice*, 2001; 15: 2: 159-164.

83) Holmberg EB, Hillman RE, Perkell JS. Glottal airflow and transglottal air pressure measurements for male and female speakers in soft, normal and loud voice. *Journal of the Acoustical Society of America*, 1988; 84: 2: 511-529.

84) Honda K. Relationship between pitch control and vowel articulation. In:. Bless DM, Abbs JH (Eds.). *Vocal Fold Physiology.* San Diego: College- Hill press, 1983: 286-299.

85) Honda K, Fujimura O. Intrinsic vowel F0 and phrase-final F0 lowering: phonological vs. biological explanations. In: Gauffin J, Hammarberg B (Eds.). *Vocal Fold Physiology, Acoustics, Perceptual and Physiological Aspects of Voice Mechanism*. San Diego: Singular Publishing Group Inc., 1991: 21-27.

86) Honjo I, Issihi N. Laryngoscopic and voice characteristics of aged persons. *Archives of Otolaryngology,* 1980; 106: 149-150.

87) Howard DM, Angus AS. Room acoustics. How they affect vocal production and perception. In: Dejonckere PH (Ed.). *Occupational Voice: Care and Cure*. Hague: Kugler Publications, 2001: 29-46.

88) Hull R. (Prof.) Wichita University, Oregon. *Personal contact,* 2000.

89) International Organization for Standardization. Ergonomic assessment of speech communication. Part 1: Speech interference level and communication distances for persons with normal hearing capacity in direct communication (SIL method), *ISO 9921-1*. Geneva: 1996; 1-10.

90) Isshiki N. Regulatory mechanism of voice intensity variation. *Journal of Speech and Hearing Research*, 1964; 7: 17-29.

91) Issihiki N, Okamura H, Tanabe M, Morimoto M. Differential diagnosis of hoarseness. *Folia Phoniatrica et Logopaedica*, 1969; 21: 9-19.

92) Iwarsson J, Sundberg J. Effects of lung volume on vertical larynx position during phonation. *Journal of Voice*, 1998; 12: 2: 159-165.

93) Jacobson BH, Johnson A, Crywalski C. The Voice Handicap Index (VHI): development and validation. *American Journal of Speech–Language Pathology,* 1997; 6: 66-70.

94) Jiang J, Titze I. Measurement of vocal fold intraglottal pressure and impact stress. *Journal of Voice*, 1994; 2: 132-144.

95) Johnson CE. Children's phoneme identification in reverberation and noise. *Journal of Speech, Language and Hearing Research*, 2000; 43: 144-158.

96) Jonsdottir V. The effects of professional demands and environmental influences on teachers' voices in North East Iceland. A thesis (M.Phil). Glasgow: Department of Speech and Language Therapy at Faculty of Education. University of Strathclyde, 1997.

97) Kitch JA, Oates J. Perceptual features of vocal fatigue as self- reported by a group of actors and singers. *Journal of Voice*, 1994; 8: 3: 207-214.

98) Kitzing P. Glottographic frequency analysis (in Swedish). *Dissertation* Lund: Lund University, 1979.

99) Kitzing P. LTAS criteria pertinent to the measurement of voice quality. *Journal of Phonetics*, 1986; 14: 477-482.

100) Kitzing P, Åkerlund L. *Änderungen der Sprechstimmlage im Stimmbelastungstest. Die Krankheit der Stimme - die Stimme der Krankheit* (in German). Stuttgart: Gustav Fischer Verlag, 1991.

101) Kitzing P, Åkerlund L. Long-time average spectrograms of dysphonic voices before and after therapy. *Folia Phoniatrica et Logopaedica*, 1993; 45: 53-61.

102) Ko N. Response of teachers to aircraft noise. *Journal of Sound and Vibration,* 1979; 62: 277- 292.

103) Kostyk BE, Rochet AP. Laryngeal airway resistance in teachers with vocal fatigue: A preliminary study. *Journal of Voice*, 1998; 12: 3: 287-290.

104) Krook MIP. Speaking fundamental frequency characteristics of normal Swedish subjects obtained by glottal frequency analysis. *Folia Phoniatrica et Logopaedica*, 1988; 40: 82-90.

105) Kyriacou C, Sutcliffe J. Teachers' stress: prevalence, sources and symptoms.

British Journal of Educational Psychology, 1978; 48 : 159-167.

106) Lallh AK, Rochet AP. The effect of information on listeners' attitudes towards speakers with voice or resonance disorders. *Journal of Speech, Language and Hearing Research*, 2000; 43: 782-795.

107) Lane H, Tranel B. The Lombard sign and the role of hearing in speech. *J. Speech Hear. Res.,* 1971; 14: 677-709.

108) Laukkanen A-M. Manipulation of auditory feedback as a possible method in speech training and therapy. A preliminary report. In: Leiwo M, Aulanko R (Eds.). Studies in logopedics and phonetics 1. Series B: *Phonetics, Logopedics and Speech Communication* Publications of the Department of phonetics, University of Helsinki, 1990; 2: 79-97.

109) Laukkanen A-M. Artificial pitch changing in auditory feedback as a possible method in voice training and therapy. *Folia Phoniatrica et Logopaedica* 1994; 46: 86-96.

110) Laukkanen A-M. On speaking voice exercises. *Dissertation*, *Tampere: Tampere University*, Finland, 1995.

111) Laukkanen A-M, Vilkman E, Alku P, Oksanen H. Physical variations related to stress and emotional state: a preliminary study. *Journal of Phonetics,* 1996; 24: 313-335.

112) Laukkanen A-M, Vilkman E, Alku P, Oksanen H. On the perception of emotions in speech: the role of voice quality. *Logopedics Phoniatrics Vocology*, 1997; 22: 4: 157-168.

113) Laukkanen A-M, Lindholm P, Vilkman E. Vocal exercising and speaking related changes in glottal resistance. A pilot study. *Logopedics Phoniatrics Vocology*, 1998; 23: 85-92.

114) Laukkanen A-M, Vintturi J, Vilkman E, Sala E, Siikki I, Lukkarila P, Sihvo M. Perceptual acoustic and self-reported correlates of vocal loading; *in Proceedings of the 25th World Congress of the International Association of Logopedics and Phoniatrics.* Montreal, 2001.

115) Lauri E-R, Alku P, Vilkman E, Sala E, Sihvo M. Effects of prolonged oral reading on time based glottal flow waveform parameters with special reference to gender differences. *Folia Phoniatrica et Logopaedica*, 1997; 49: 234-246.

116) Leavitt H. The acoustics of speech production. In: Ross M, Giolas T (Eds.).

Auditory Management of Hearing Impaired Children: Principles and Prerequisites for Invention. Baltimore: University park Press, 1978.

117) Leavitt R, Flexer C. Speech degradation as measured by the rapid speech transmission index (RASTI) *Ear and Hearing*, 1991; 12: 115-118.

118) Lehman A, Gratiot A. Effects du bruit sur les enfants a lécole. Proceedings of the 4th congress on noise as a public health problem. *Milano Centro ricerche e studi Amplifon,* 1983: 859-862.

119) Leventhall G. Current North American concerns on schoolroom acoustics for children with hearing disabilities. *Proceedings Institute of Acoustics*, 1998; 20: 4: 43-47.

120) Lieberman P. *Intonation, Perception and Language*. Cambridge, Mass., 1967.

121) Luchsinger R, Arnold GE. *Voice, Speech and Language.* London: Constable, 1965.

122) Löfqvist A. The Long-term-average-spectrumas a tool in voice research. *Journal of Phonetics,* 1986; 14: 471-475.

123) Löfqvist A, Manderson B. Long-term-average-spectrumof speech and voice analysis. *Folia Phoniatrica et Logopaedica*, 1987; 39: 221-229.

124) MacKenzie DJ. Classroom acoustics – the way ahead. *Proceedings Institute of Acoustics*, 1998; 20: 4.

125) Masuda T, Yoshimitu I, Manako H, Komiyama S. Analysis of vocal abuse: Fluctions in phonation time and intensity in 4 groups of speakers. *Acta Oto-Laryngologica. (Stockh),* 1993; 113: 547-552.

126) McCormick L and Schiefelbusch R. *Early Language Intervention*, Columbus: Merill Publishing, 1984.

127) Mann EA, McClean MD, Gurevich-Uvena J, Barkmeier J, McKenzie-Garner P, Paffrath J, Patow C. The effects of excessive vocalization on acoustic and videostroboscopic measures of vocal fold condition. *Journal of Voice,* 1999; 13: 2: 294-302.

128) Markides A. Speech Levels and Speech-to-Noise Ratios. *British Journal of Audiology*, 1986; 20: 115-120.

129) Martin S. *Working with Dysphonics.* Oxford: Winslow Press, 1987.

130) Martin S. Voice Forum: Voice Care and Development for Teachers: Survey

Report. *Voice,* 1994; 3: 92-98.

131) McCroskey F, Devens J. Acoustic characteristic of public school classrooms constructed between 1890 and 1960. In: Noisexpo Proceedings 101-103.

132) McGlashan JA, Howard DM. Theoretical and practical considerations in the occupational use of voice amplification devices. In: Dejonckere PH (Ed.). *Occupational Voice: Care and Cure*. Hague: Kugler Publications, 2001: 165-185.

133) Moodley A. Acoustic condition in mainstream classrooms. *Journal of the British Association of Teachers of the Deaf,* 1989; 13: 2: 48-54.

134) Moncur J, Dirks D. Binaural and monaural speech intelligibility in reverberation. *Journal of the Acoustical Society of America,* 1967; 81: 186-195.

135) Morton V, Watson DR. The teaching voice: Problems and perceptions. *Logopedics Phoniatrics Vocology*, 1998; 23: 3: 133-139.

136) Morton V, and Watson DR; Voice in the classroom. In: Dejonckere PH (Ed.). *Occupational Voice: Care and Cure*. Hague: Kugler Publication, 2001: 53-69.

137) Murphy CH, Philip CD. The effects of cigarette smoking on voice-fundamental frequency. *Otolaryngology and Head Neck Surgery,* 1987; 4: 376-380.

138) Neils LR, Yairi E. Effects of speaking in noise on vocal fatigue and vocal recovery. *Folia Phoniatrica et Logopaedica*, 1987; 39: 104 -112.

139) Newman S-R, Butler J, Hammond EH, Gray SD. Preliminary report on hormone receptors in the human vocal fold. *Journal of Voice,* 2000; 14: 72-81.

140) Novak A, Dlouha O, Capova B, Vohradnik M. Voice fatigue after theatre performance in actors. *Folia Phoniatrica et Logopaedica,* 1991; 43: 74–78.

141) Ohlson A-C. Voice and work environment: Towards an ecology of vocal behaviour. *Dissertation.* Gothenburg: University of Gothenburg, 1988.

142) Ohlson, A-C. Voice Forum: Prevention Voice Care for Teachers. *Voice,* 1993; 2: 112-115.

143) Otting S, Smaldino J, Plakke B, Bozik M. Comparison of two methods of improving classroom S/N ratio. *Paper presented at the American Speech,*

Language and Hearing Association Convention, San Antonio TX, 1992.

144) Palmer CV. Quantification of the ecobehavioral impact. *Language and Hearing Research*, 1998; 41: 819-833.

145) Pekkarinen E. Effects of noise and reverberation on speech discrimination. *Dissertation*. Turku: Turku University, 1988.

146) Pekkarinen E, Viljanen V. Effect of sound-absorbing treatment on speech discrimination in rooms. *Audiology*, 1990; 29: 219 – 227.

147) Pekkarinen E, Himberg L, Pentti J. Prevalence of vocal symptoms among teachers compared with nurses: A questionnaire study. *Scandinavian Journal of Logopedics and Phoniatrics*, 1992; 17: 2: 113-117.

148) Rantala L, Haaja K, Vilkman E, Körkkö P. Practical arrangements and methods in the field examination and speaking style analysis of professional voice users. *Scandinavian Journal of Logopedics and Phoniatrics.,* 1994; 19: 43-54.

149) Rantala L, Määttä T, Vilkman E. Measuring voice under teachers' working circumstances: F0 and perturbation features in maximally sustained phonation. *Folia Phoniatrica et Logopaedica*, 1997; 49: 281-291.

150) Rantala L, Lindholm P, Vilkman E. F0 changes due to voice loading under laboratory and field conditions. A pilot study. *Logopedics Phoniatrics Vocology*, 1998; 23: 164-168.

151) Rantala L and Vilkman E. Relationship between subjective voice complaints and acoustic parameters in female teachers' voices. *Journal of Voice* , 1999; 13: 4: 484 – 495.

152) Raven BE. *Psychogenic Voice Disorders & Cognitive Behaviour Therapy*. London: Whurr, 1993.

153) Rosenberg G, Blake-Rahter P, Allen L, Redmond B. Improving classroom acoustics: A multi-district pilot study on FM classroom amplification. *Poster session presented at the American Academy of Audiology annual convention*, Richmont. VA ; 1994.

154) Rosenberg G, Blake-Rahter P. Sound-field amplification: A review of the literature. In: Crandell C, Smaldino J, Flexer C (Eds.) *Sound-Field FM Amplification: Theory and Practical Applications*. San Diego: Singular Publishing Group, Inc., 1995: 107-123.

155) Roy N, Gray SD, Simon M, Dove H, Corbin-Lewis K, Stemple JS. An

evaluation of the effects of two treatment approaches for teachers with voice disorders: A prospective randomised clinical trial. *Journal of Speech, Language and Hearing Research*, 2001; 44: 286-296.

156) Roy N, Weinrich B, Gray SD, Tanner K, Toledo AW, Dove H, Corbin-Lewis K, Stemple JC. Voice amplification versus vocal hygiene instruction for teachers with voice disorders: A treatment outcomes study. *Journal of Speech, Language and Hearing Research*, 2002; 45: 626-638.

157) Russel A, Oates J, Greenwood KM. Prevalence of voice problems in teachers. *Journal of Voice*, 1998; 12: 4: 467-79.

158) Sala E, Laine A, Simberg S, Pentti J, Suonpää J. The prevalence of voice disorders among day care center teachers compared with nurses. A questionnaire and clinical study. *Journal of Voice,* 2001; 15: 3: 413–423.

159) Sala E, Airo E, Olkinuora P, Simberg S, Ström U, Laine A, Pentti J, Suonpää J. Vocal loading among day care center teachers. *Logopedics Phoniatrics Vocology*, 2002; 27: 1: 21-28.

160) Sander EK and Ripich DE. Vocal fatigue. *Annals of Otolaryngology, Rhinology and Laryngology*, 1983; 92: 141-145.

161) Sanders D. Noise conditions in normal school classrooms. *Exceptional Child,* 1965; 31: 344–353.

162) Sapienza CM, Crandell C, Curtis B. Effects of sound-field frequency modulation amplification on reducing teachers' sound pressure level in the classroom. *Journal of Voice*, 1999; 13: 3: 375-381.

163) Sapir S, Attias J, Shahar A. Vocal attrition related to idiosyncratic dysphonia: Re-analysis of survey data. *European Journal of Disorders of Communication*, 1992; 27: 129-135.

164) Sapir S, Keidar A, Mathers-Schmidt B. Vocal attrition in teachers: survey findings. *European Journal of Disorders of Communication*, 1993; 28: 177-185.

165) Sarff L. An innovative use of free-field amplification in classrooms. In: Roeser R, Downs M (Eds.). *Auditory Disorders in School Children.* New York: Thieme-Stratton, 1981: 263-272.

166) Sataloff RT. Molecular and cellular structure of vocal fold tissues; response. In: Titze IR (Ed.). *Vocal Fold Physiology, Frontiers in Basic Science*. San Diego, California: Singular Publishing Group, Inc., 1993: 1-35.

167) Sataloff RT. Vocal tract response to toxic injury: Clinical issues. *Journal of Voice*, 1994; 8: 1: 63-64.

168) Scherer RC, Titze IR, Raphael BN, Wood RP, Ramig LA, Blager FB. Vocal fatigue in a trained and an untrained voice user. In: Baer T, Sasaki C, Harris KS (Eds.). *Vocal Fold Physiology: Laryngeal Function in Phonation and Respiration*. Boston: College - Hill Press, 1987: 533-555.

169) Schmidt CP, Andrews ML, McCutcheon JW. An acoustical and perceptual analysis of the vocal behaviour of classroom teachers. *Journal of Voice,* 1998; 12: 4: 434-443.

170) Seidner W. Objektive qualitätsbeurteilung der stimme mittels dynamicmessungen. *Zeitschrift für klinische Medizin*.1986; 40: 1521-1525.

171) Sherman D, Jensen R. Harshness and oral reading time. *Journal of Speech and Hearing Research*, 1962; 27: 172-177.

172) Sihvo M. Voice in test. *PhD thesis*. *Acta Universitatis Tamperensis* 541. Tampere: University of Tampere, 1997.

173) Siegert C. Zur problematik der funktionellen stimmstörungen bei pädagogischen berufssprechern (In German). *Deutsche Gesundheitswesen,* 1965; 21: 969.

174) Smith E, Verdolini K, Gray S, Nichols S, Lemke J, Barkmeier J, Dove H, Hoffman H. Effect of voice disorders on quality of life. *Journal of Medical Speech-Language Pathology.,* 1996; 4: 4: 223-244.

175) Smith E, Gray S, Dove H, Kirchner, L Heras H. Frequency and effects of teachers' voice problems. *Journal of Voice*, 1997; 11: 1: 81-87.

176) Smith E, Lemke J, Taylor M, Kirchner L, Hoffman H. Frequency of voice problems among teachers and other occupations. *Journal of Voice,* 1998 (a); 12: 4: 480-488.

177) Smith E, Kirchner L, Taylor M, Hoffman H, Lemke J. Voice problems among teachers: Differences by gender and teaching characteristics. *Journal of Voice*, 1998 (b); 12: 3: 328-334.

178) Sonninen A. The external frame function in the control of pitch in the human voice. *Annual of the New York Academy of Sciences*, 1968; 155: 68-89.

179) Sonninen A, Damsté PH, Jol J, Fokkens J, Roelofs J. Microdynamics in vocal fold vibration. *Acta Oto-Laryngologica*, 1974; 78: 129-134.

180) Stemple JC, Stanley J, Lee L. Objective measures of voice production in normal subjects following prolonged voice use. *Journal of Voice,* 1995; 9: 2: 127-133.

181) Stoicheff ML. Voice following Radiotherapy. *The Laryngoscope*, 1976: 608-618.

182) Stone R, Sharff D. Vocal change associated with the use of atypical pitch and intensity levels. *Folia Phoniatrica et Logopaedica*, 1973; 25: 91-103.

183) Stone RE, Rainey CL. Intra and intersubject variability in acoustic measures of normal voice. *Journal of Voice*, 1991; 5: 3: 189-196.

184) Sundberg J. *The Science of the Singing Voice*. Illinois: Northern Illinois University Press Dekalb, 1987.

185) Sundberg J, Ternström , Perkins WH, Gramming P. Long-Term-Average spectrum analysis of phonatory effects of noise and filtered auditory feedback. *STL-QPSR*, 1987:1:57-80

186) Sundberg J, Titze I, Sherer R. Phonatory control in male singing; A study of the effects of subglottal pressure, fundamental frequency and mode of phonation on the voice source. *Journal of Voice*, 1993; 7:1:15-29.

187) Sundell J. *Indoor Air, International Journal of Indoor Air Quality and Climate*. Stockholm: Karolinske Institute, Institute of Environmental Medicine, 1994: May.

188) Titze IR. Parameterization of glottal area, glottal flow, and vocal fold contact area. *Journal of the Acoustical Society of America.,* 1984; 75: 2: 570-580.

189) Titze IR. Physiologic and acoustic differences between male and female voices. *Journal of the Acoustical Society of America*, 1989; 85: 1699-1707.

190) Titze IR. Acoustic interpretation of the voice range profile (phonetogram). *Journal of Speech and Hearing Research,* 1992; 35: 21-34.

191) Titze I. *Principles of Voice Production*. Englewood Cliffs, N.J.:Prentice - Hall, 1994.

192) Titze IR, Lemke J, Montequin D. Population in the U.S. Workforce who rely on voice as a primary tool of trade: A preliminary study. *Journal of Voice*, 1997; 11: 3: 254-259.

193) Unger E, Bastien H-J. Professionelle Dysphonien (in German), *Deutsche*

Gesundheitswesen, 1981; 36: 1461-1464.

194) Van Heusden E, Plomp R, Pols LCW. Effect of ambient noise on the vocal output and the preferred listening level of conversational speech. *Applied Acoustics,* 1979; 12: 3-43.

195) Van Summers W, Pisoni DB, Bernacki RH, Pedlow RI, Stokes MA. Effects of noise on speech production: Acoustic and perceptual analyses. *JASA*, 1988; 84: 3: 917-928.

196) Verdolini K, Titze IR, Druker DG. Changes in phonation threshold pressure with induced conditions of hydration. *Journal of Voice,* 1990; 4: 2: 142-151.

197) Verdolini K, Ramig LO. Review: Occupational risk for voice problems. *Logopedics Phoniatrics Vocology*, 2001; 26:1:37-46.

198) Vilkman E, Karma P. Vertical hyoid bone displacement and fundamental frequency of phonation. *Acta Oto-Laryngologica.* (Stockh) 1989; 108: 142-151.

199) Vilkman E. Occupational risk factors and voice disorders. *Logopedics Phoniatrics Vocology,* 1996; 21: 137-141.

200) Vilkman E, Lauri E-R, Alku P, Sala E, Sihvo M. The effects of prolonged reading on F0 , SPL, subglottal pressure and amplitude characteristics of glottal flow waveform. *Journal of Voice*, 1999; 13: 2: 305-315.

201) Vilkman E. Voice problems at work: A challenge for occupational safety and health arrangement. *Folia Phoniatrica et Logopaedica*, 2000; 52: 120-125.

202) Vilkman E. A survey on the occupational safety and health arrangements for voice and speech professionals in Europe. In: Dejonckere P (Ed.). *Occupational Voice: Care and Cure*. Hague: Kugler Publications, 2001: 129-137.

203) Vilkman E, Alku P, Vintturi J. Dynamic extremes of voice in the light of time domain parameters extracted from the amplitude features of glottal flow and its derivative. *Folia Phoniatrica et Logopaedica*, 2002; 54: 144-157.

204) Vinnueftirlit ríkisins (Administration of occupational Safety and Health in Iceland). *Inniloft og líðan fólks* (in Icelandic). Reykjavík: Administration of occupational Safety and Health in Iceland, 1990.

205) Vintturi J. Studies on voice production with a special emphasis on vocal loading gender, some exposure factors and intensity regulation. Dissertation.

Helsinki: Helsinki University, 2001.

206) Vintturi J, Alku P, Lauri E-R, Sala E, Shivo M, Vilkman E. Objective analysis of vocal warm-up with special reference to ergonomic factors. *Journal of Voice*, 2001;15:1:36-53.

207) Wanzer MB, McCroskey JC. Teacher socio-communicative style as a correlate of student affect towards teacher and course material. *Communication Education*, 1998; 47: 43-166.

208) Webster JC. Effects of noise on speech. In. *Handbook of Noise Control*. New York: McGraw - Hill. 1979; Chapter 14.

209) Zagoruiko N, Tambovtsev Y. Aspects of human performance in an intensive speech task. *International Journal of Man-Machine Studies.*, 1982; 16: 173-181.

210) Zwicker E, Fastl H. *Psycho-Acoustics. Facts and Models,* 2nd Ed. New York: Springer-Verlag, 1999.

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Valdís Ingibjörg Jónsdóttir

APPENDIX:

1 QUESTIONNNAIRE FOR TEACHERS

1. **Female** ____________ **Male** ______________

2. **Age** ________________________________

3. **PROFESSIONAL BACKGROUND**

   a) Teaching responsibilities (e.g., subjects taught)
   ____
   ____
   ____
   ____

   b) Teaching experience__________________years

   VOICE USE
   a) How many class hours a week do you teach? ___________________

   b) Do you work as a travel guide?
   How many hours a day?_________How many weeks a year?_________

   c) Do you do some acting ?
   How many hours a day?_________How many weeks a year?_________

   d) Do you work as a coach ?
   How many hours a day?_________How many weeks a year?_________

   e) Other types of work requiring voice use ?
   Which____
   How many hours a day?__________How many weeks a year_________

   Please underline appropriate
   Activities which may affect voice:

4. **Do you take part in sports where you are required to shout ?**
   Often Occasionally Seldom Never

5. **Do you take part in aerobics where you are required to shout ?**
   Often Occasionally Seldom Never

6. **Do you go to sports competition where you are required to shout ?**
   Often Occasionally Seldom Never

Please tick as appropriate
Consumer habits that may affect the mucous membranes:

7. Do you smoke?

   a. Twenty or more a day
   b. Ten - twenty a day
   c. Less than 10 a day
   d. Occasionally
   e. Have given up smoking. How long ago?
   f. Have never smoked

8. Coffee:
   How many cups of coffee do you drink each day, approximately?_______

   Please underline appropriate
   Medicine may affect the mucous membranes:

9. a) Have you used in the past year any nasal sprays which are known to dry out the mucous membranes?
   Always Often Occasionally Seldom Never

   b) Do you take steroids or other hormonal medicines?
   Always Often Occasionally Seldom Never

   c) Do you take medicines for high blood pressure?
   Always Often Occasionally Seldom Never

   Please tick as appropriate
   Medical condition that may affect your voice:

10. a) Do you suffer from allergies?
    b) Do you suffer from asthma?
    c) Do you suffer from hearing loss?
    d) Do you suffer from gastro-oesophageal reflux?

    Medical history

11. Have you been to a ear nose and throat specialist because of your voice?
    a) How often in your career? ______________
    b) Did you require medical treatment?
    Yes ________No_______
    c) Did you require treatment from speech pathologist
    Yes _______No_____

12. Have you had flu more than four times a year ?
Yes________ No_______

Voice training is important for using your voice properly

13 a) Have you ever had any vocal training, e.g., singing lessons ?
If so, for how many years _____________

b) Have you been in a choir?
If so, for how many years? _____________

Keys to questions 14
Please tick as appropriate

1. Hardly ever (i.e. less than once or twice a year)
2. Seldom (i.e. up to four or five times a year)
3. Sometimes (i.e. about once a month)
4. Often (i.e. every week)
5. Almost always (i.e. every day)

14. **Do you experience?:**

Dry throat	1	2	3	4	5
Sore throat	1	2	3	4	5
Tickly throat	1	2	3	4	5
Lump in the throat	1	2	3	4	5
Hoarseness without a cold	1	2	3	4	5
Voice failure (pitch breaks) while teaching	1	2	3	4	5
Voice failure when not suffering from a cold	1	2	3	4	5
Voice fails to project in noisy surroundings	1	2	3	4	5
Voice fails to last in teaching	1	2	3	4	5
Voice fatigue while reading	1	2	3	4	5
Voice fatigue while singing	1	2	3	4	5
Voice fatigue in conversation	1	2	3	4	5

Aching shoulders	1	2	3	4	5
Back ache	1	2	3	4	5
Muscular ache in the neck	1	2	3	4	5

15. When do you suffer from these symptoms? Please tick as appropriate

In the evenings	Always	Often	Occasionally	Seldom	Never
In the mornings	Always	Often	Occasionally	Seldom	Never
During the weekends	Always	Often	Occasionally	Seldom	Never
During the autumn	Always	Often	Occasionally	Seldom	Never
During the winter	Always	Often	Occasionally	Seldom	Never
During the spring	Always	Often	Occasionally	Seldom	Never
While teaching	Always	Often	Occasionally	Seldom	Never
During the summer	Always	Often	Occasionally	Seldom	Never

16 Have you taken time off from work because
your voice failed?
Yes______________No_____________

17. ***Please tick as appropriate.***
Have you been concerned that your pupils have sometimes had difficulty in hearing you?
Always Often Occasionally Seldom Never

It is known that stress can affect voice quality.

18. Please mark on a scale of 8 the degree to which you find teaching stressful**:**
1 2 3 4 5 6 7 8

19. How would you describe your own voice?:

2 QUESTIONNAIRE FOR TEACHERS

Date ___________ Year ______________________

Gender _______________ Class _____________________

1. For how many class hours have you been using the amplifying system _________?

2. Are there advantages for the teacher in using a microphone?:

Considerable ______ Fairly________ Not much________None__________

Advantages (*please tick to appropriate*):

3. Is it easier to speak?

Considerably ______ Fairly________ Not much________Not__________

4. Do you think pupils pay more attention?

Considerably ______ Fairly________ Not much________No_________

5. Less chatter in classroom?

Considerably ______ A fair amount______Not much________No______

6. Do you have to repeat yourself if you use an amplifying system?

Considerably ______ A fair amount______Not much________None______

7. Do you have to repeat yourself if you don't use an amplifying system?

Considerably ______ A fair amount______Not much________None______

8. Do you talk more if you are using an amplifying system?

Considerably ______ A fair amount______Not much________None______

9. Do you find any differences in your voice use if you use amplifying system? How?

____

____

____

____

10. Do you feel physically less fatigued if you are using the amplifying system?
Considerably ______ A fair amount______Not much________None______

11. Do you feel less fatigue in your vocal mechanism if you are using an amplifying system?
Considerably ______ A fair amount______Not much________None______

12 In which part of the vocal mechanism do you feel fatigue ?
A) When you are using the amplifying system
_____Tongue______Lips_________Jaws__________Pharynx

B) When you do not use amplifying system
_____Tongue______Lips_________Jaws__________Pharynx

13 Describe in a few words possible disadvantages of using amplification

3 STUDENTS' QUESTIONNAIRE

Date............................. year....................

Male………. Female ………

Subject..................................

Class ....

School...............................

Please underline the appropriate word(s):

Is it better when the teacher is using amplification?
very much better much better a little better no better

Advantages:

When the teacher is using amplification -

Is listening easier?
very much easier much easier a little easier not easier

Is it easier to follow the lessons?
very much easier much easier a little easier not easier

Is there less class chatter?
very much less much less a little less no less

Is it easier to hear the teacher through class chatter?
very much easier much easier a little easier not easier

Are there fewer repetitions from the teacher?
very many fewer many fewer just a few no fewer

Is it easier to concentrate on the lessons?
very much easier much easier a little easier not easier

Do you find the lessons more interesting?
very much much a little not

Would you remind your teacher to use the amplification if she/ he forgot to turn it on? Yes_____ No ____ Don't know_________

Write down one or two sentences about what seem to you to be the advantages of using amplification.
....
....
....

Disadvantages

Do you find amplification
very annoying annoying a little annoying not annoying

Do you find the amplification equipment uncomfortably noisy?
very noisy noisy a little noisy not noisy

Write down one or two sentences about what seem to you the disadvantages of the use of amplification
....
....
....
....
....
....
....

Any other comments
....
....
....
....
....
....

TIIVISTELMÄ

Opettajilla ympäri maailman esiintyy paljon ääniongelmia. Epäsuotuisia äänenkäyttöolosuhteita (suuret luokkahuoneet, huonot akustiset olosuhteet, taustamelu) pidetään keskeisenä syynä ongelmiin. Ne myös vaikuttavat negatiivisesti oppilaiden kuuntelumahdollisuuksiin (huono signaali-kohina-suhde ja taustamelu). Huonoista äänenkäyttöolosuhteista aiheutuu usein äänihuulia kuormittava äänenkäyttötapa (kohonnut F0, SPL ja hyperfunktionaalinen äänentuotto), jossa äänihuulten välinen törmäyspaine on suuri. Tästä voi seurata äänen väsymistä ja jopa patologisia muutoksia äänihuulikudokseen.

Tässä tutkimuksessa tarkasteltiin sähköisen äänenvoimistuksen käyttöä luokkahuoneessa eräänä mahdollisena keinona parantaa opettajien ääniergonomiaa ja oppilaiden kuunteluolosuhteita. Tutkimus koostuu viidestä kansainvälisessä tieteellisessä aikakausilehdessä julkaistusta artikkelista.

Tutkimuksessa tarkasteltiin (1) kuullun äänen sähköisen voimistamisen sekä korvatulppien avulla tapahtuvan vaimentamisen vaikutuksia puheäänen parametreihin laboratorio-olosuhteissa, (2) kuullun äänen sähköisen voimistamisen vaikutuksia opettajien äänen parametreihin luokkahuonepuheessa ja (3) kerättiin kyselylomakkeiden avulla tietoa oppilaiden/opiskelijoiden ja opettajien mielipiteistä sähköisen äänenvoimistuksen käytöstä.

Laboratorio-olosuhteissa äänitettiin kuutta naispuolista (suomalaista) koehenkilöä, joilla ei tiedetty olevan äänen tai kuulon ongelmia. Luokkahuoneolosuhteissa äänitettiin viittä islantilaista opettajaa (3 naista, 2 miestä), joilla kaikilla oli eriasteisia ääniongelmia, muttei orgaanisia muutoksia äänihuulissa. Kyselytutkimukseen osallistui 33 islantilaista opettajaa (26 naista, 7 miestä) ja 791 oppilasta/opiskelijaa (446 naispuolista, 345 miespuolista). Tutkimukseen osallistui opettajia sekä peruskoulusta, lukiosta että yliopistosta.

Koehenkilöt lukivat laboratorio-olosuhteissa saman tekstin (133 sanaa, ei /s/-äännettä) kaksi kertaa peräkkäin 1.(a) normaaliolosuhteissa ja (b) oma ääni voimistettuna kuulokkeissa ja 2. (a) normaaliolosuhteissa ja (b) korvatulpat korvissa. Testien 1 ja 2 välillä oli aikaa 2 - 6 kk. Molemmat testit toistettiin aamupäivällä ja iltapäivällä ja kolmena eri päivänä (ensimmäiset kokeet peräkkäisinä päivinä, kolmas kerta viikon kuluttua). Näytteistä analysoitiin F0 ja SPL (sekä kokonais-SPL että eri taajuuskaistojen SPL-arvot) Intelligent Speech Analyser (ISA) -puheanalyysilaitteistolla, jonka on kehittänyt DI Raimo Toivonen.

Opettajat äänittivät kannettavalla Dat-nauhurilla ja pääpantamikrofonilla luokkahuonepuhettaan viikon raskaimman työpäivän ensimmäisellä ja viimeisellä oppitunnilla kahtena päivänä viikon välein, ensimmäisellä kerralla ilman äänenvoimistusta, seuraavalla viikolla käyttäen luokassa sähköistä äänenvoimistusta. Ennen toista äänitystä opettajat totuttelivat äänenvoimistuksen käyttöön viikon verran.

Oppituntipuheesta analysoitiin kultakin oppitunnilta 4 minuuttia (artikkelit II ja IV) tai 2 minuuttia (artikkeli V) tunnin alusta, keskeltä ja lopusta. Näytteistä mitattiin F-J Electronicsin analogisella mittarilla F0 ja SPL (Artikkelit II ja IV) ja laskettiin fonaatioaika sekä tehtiin ISA:lla keskiarvospektrianalyysi (artikkeli V).

Tulosten perusteella F0 ja SPL laskivat sekä käytettäessä sähköistä äänenvoimistusta että kuullun äänen vaimennusta korvatulpilla. Sähköistä äänenvoimistusta käytettäessä myös spektriä kuvaavat alfa-suhdeluku ja F1:n ja F0:n välinen tasoero pienenivät eli spektrin kaltevuus jyrkkeni. Fonaatioaika ei muuttunut merkitsevästi. Opettajan työpäivän aikana tapahtuva F0:n, SPL:n ja spektrin kaltevuuden loiveneminen oli normaalitilanteeseen verrattuna suurempaa käytettäessä sähköistä äänenvoimistusta. Enemmistö opettajista ja oppilaista/opiskelijoista piti sähköistä äänenvoimistusta luokkahuoneessa hyödyllisenä. Opettajien oli mielestään helpompi puhua ja he kokivat vähemmän äänenväsymisoireita voimistusta käytettäessä. Oppilaat ilmoittivat, että heidän oli helpompi kuulla opettajan puhetta ja seurata opetusta. Haitoiksi mainittiin lähinnä tekniset ongelmat, jotka useimmiten johtuivat opettajan puutteellisesta taidosta käyttää äänenvahvistuslaitteistoa.

Tulokset viittaavat siihen, että sähköisen äänenvoimistuksen käyttö pienentää äänielimistöön kohdistuvaa kuormitusta opettajan työpäivän aikana. Mitattujen ääniparametrien kasvu työpäivän aikana näyttää heijastavan normaalia adaptaatiota äänelliseen kuormitukseen, sillä muutokset olivat suurempia ja koettu äänen väsyminen pienempää käytettäessä sähköistä äänenvahvistusta.

Tulosten perusteella näyttäisi olevan syytä tarjota opettajille mahdollisuus sähköisen äänenvoimistuksen käyttöön luokkahuoneissa. Huomiota pitäisi kiinnittää sekä siihen, että laitteisto soveltuu tilaan, jossa sitä käytetään että opettajien riittävään käytönopastukseen.