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Changes in Objective Acoustic Measurements and Subjective Voice Complaints in Call Center Customer-Service Advisors During One Working Day

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Summary: The aim of this study was to investigate how different acoustic parameters, extracted both from speech pressure waveforms and glottal flows, can be used in measuring vocal loading in modern working environments and how these parameters reflect the possible changes in the vocal function during a working day. In addition, correlations between objective acoustic parameters and subjective voice symptoms were addressed. The subjects were 24 female and 8 male customer-service advisors, who mainly use telephone during their working hours. Speech samples were recorded from continuous speech four times during a working day and voice symptom questionnaires were completed simultaneously. Among the various objective parameters, only F_0 resulted in a statistically significant increase for both genders. No correlations between the changes in objective and subjective parameters appeared. However, the results encourage researchers within the field of occupational voice use to apply versatile measurement techniques in studying occupational voice loading.

Key Words: Occupational voice—Voice loading—Voice symptoms—Acoustic voice analysis—Inverse filtering—Field study.

INTRODUCTION

Professional voice users constitute the majority of patients at voice clinics.[1,2] Their voice problems can be labeled occupational voice disorders because the symptoms these individuals suffer from are likely to be caused by exposure at work. The risk factors in voice professions include background noise, unsatisfactory acoustics, large speaking distance, poor quality of air (dryness, dust), unfavorable working posture, and vocal loading *per se* from speaking or singing.[3] The prevalence of work-related voice problems has led to the introduction of the term vocal loading, widely defined as prolonged use of voice.[4] Vocal loading is measured in terms of time and intensity; the longer and louder a person has to talk, the greater the strain on the voice and the more vocal capacity needed.[5]

Human voice production is a combination of anatomical structures, physiological mechanisms, and acoustic output, which are unique to each speaker. In addition, personality and psychological issues such as stress and anxiety influence person's voicing habits. Voice disorders may involve an abnormality of the larynx, which causes the laryngeal

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mechanism to fail to meet the functional vocal needs of the speaker. The examination of voice disorders typically involves measures such as structural, physiological, acoustic, and audio-perceptual analyses.[6] In addition, an informative means to examine voice production is to ask speakers to score their subjective voice symptoms.

Due to an increasing number of employees working in professions in which voice is the main tool of trade, occupational voice research has become an increasingly important area of speech science, where especially the effects of vocal loading have been studied with growing interest in recent years. Overall, the studies conducted differ from one another in terms of the loading task and the recording environment. In some investigations, natural speech produced at work has been used as the loading task and the speech samples have been recorded either while working[7–11] or directly before and after it.[12–15] Other studies have been conducted by using a specific speaking task with data collection being performed in a laboratory environment.[16–23]

If data are collected only in controlled laboratory conditions, one might speculate how closely they represent real-life speaking situations at work. It is obvious that laboratory test conditions often differ markedly from real-life working situations where environmental factors such as humidity and dust, besides individual factors such as stress and communicative interaction, play a considerable role in voice performance.[21] In addition, the strain imposed on the voice mechanism in laboratory environments (eg, reading a given text) might not be entirely similar to, and thus not comparable with, the potential strain resulting from speaking at work. This might be the case even if the volume of voice production or the background noise of the environment in the two conditions were the same.[24] However, collection of speech material in real working environments engenders many challenges as well. Firstly, the level of background noise must be possible to measure.[25,26] Placing a microphone very close to the speaker's lips will reduce this problem, although not eliminate it completely. Secondly, in field studies it is important that the measurement device is easy to wear and practical to use because the subject usually needs to move around during the recordings.

Voice use at work has been studied with various methods to extract information about speech sounds. One line of research has used different types of "accumulators" or "dosimeters."[27–30] These are wearable devices to measure the vocal dose on work tasks and other daily activities.[29,31–34] The accumulator software is designed to estimate sound pressure level (SPL), fundamental frequency (F_0), and phonation time. The use of the accumulator suffers from the drawback that it typically stores only the measured quantities but not the entire speech waveform. Therefore, later analyses of the recorded voice samples are not possible. In addition, an accumulator measures only the mean values of parameters and does not give detailed information on the temporal changes of the parameters that might have occurred during the working day. However, there are also a number of experiments that have used portable DAT recorders in field studies. With this device it is possible to record the sounds to be analyzed later with the added advantage that DAT recorders have proven easy to wear and use.[10] Specifically, the average values of F_0 and SPL have been used to describe voice function during a working day[10,24] and to compare how these values change between the first and last lessons of a teacher's working day.[7,9,11,35]

The present study is part of an occupational voice project, which was launched on the basis of an initiative taken by the largest Finnish telecommunications operator Sonera (currently known as TeliaSonera Finland Oyj). It was prompted by the fact that the sick leave statistics of the company showed an overrepresentation of customer-service advisors (CSA) and it was hoped that gathering information on the working conditions in a call center would help to shed light on the background of this problem. In addition, telephone marketers constitute a special subgroup of employees because their working ability depends exclusively on their voice. On the telephone, the speaker must rely solely on his/her voice, without support from body language or written communication. Furthermore, in many companies there is currently a tendency to reorganize or even outsource customer-advising services. This will most likely result in an increasing number of call center attendances.

Previous studies on acoustic parameter changes during a working day have analyzed only a few parameters to measure workload changes in voice. In addition, only few of the previous studies have analyzed recordings made during a real working day.[7–11] Given the restrictions of the previous studies, the present study aims to enrich the view substantially by introducing the use of a wide palette of objective acoustic parameters in the measurement of occupational vocal loading. Hence, the primary goal of this study was to investigate, in cooperation with call center personnel, how different acoustic parameters can be used in measuring vocal loading in modern working environments and how these parameters reflect the possible changes in the vocal function during a working day. Voice samples were recorded at four times during a working day from natural speech and analyzed by means of an analysis program developed for continuous speech.[36,37] Parameters extracted from the input signal included F_0, SPL, the ratio between the spectral energy below and above 1000 Hz (alpha ratio, AR), and speech segment information such as the ratio of speech to silence. The number of vocal fold vibrations (Index $= F_0 \times$ voiced speech time) was also measured. To gain knowledge of the functioning of the vocal folds, an inverse filtering (IF) method was used. IF has been developed to estimate the source of voiced speech, the glottal volume velocity waveform. Hence, it aims to describe voice production at the level of vocal folds. The parameters representing IF in the present study are the normalized amplitude quotient (NAQ), amplitude quotient (AQ),[38] and the level difference between the first and the second harmonic of the glottal source spectrum (H1H2).[39] To the best of our knowledge, no previous study has analyzed acoustic features from real-work speaking situations with as wide a palette of measurement techniques as those in the present study.

In addition, the study also aims to combine objective, acoustic parameters with subjective measures of vocal symptoms. Therefore, the second goal was to find out whether any of the objective measures would correlate with work-related subjective vocal symptoms. To serve this goal, the subjects answered a questionnaire about their voice symptoms. The questionnaire was completed at the same times that the recordings of the speech samples were made.

MATERIAL AND METHODS

Subjects

The subjects of this study were 24 female and 8 male CSA, who almost exclusively use the telephone during their working hours. The length of the working day was 8 hours, including a 30-minute lunch break and two 10-minute coffee breaks. According to the representative of the employer, a CSA is estimated to spend 5 hours per day exclusively in a speaking task. The subjects worked in an open-plan office, where individual working spaces are separated by movable partition walls. According to a work environment hygiene survey conducted by the Oulu Regional Institute of Occupational Health, the background noise level in the working space was 42 dB(A). The authorities of this local institute considered the background noise level low for open office work (Table 1).

The subjects were asked about a variety of personal background factors that might affect the voice, eg, hobbies including intense voice use, smoking, hearing loss, gastroesophageal disease, and previous voice therapy. The subjects were also examined by a phoniatrician at the beginning of the study. This phoniatric examination included perceptual voice analysis and laryngeal examination with a mirror. Both the collection of the background factors and the phoniatric evaluation were performed to get a comprehensive view of the

TABLE 1. *Background Variables of the Subjects*

		Age (years)		Working Experience		
Gender	***n***	**Mean**	**Range**	**Mean**	**Range**	**Smoking**
Females	24	28	21–41	7 months	1 month to 10 years	no 66%, yes 34%
Males	8	27	21–38	8 months	5 months to 1 year	no 57%, yes 43%

health status of the subjects. The effects of the background variables were studied in a recent investigation by Lehto et al[40] and it was shown that they had no specific influence on subjective voice complaints. In the phoniatric examination, the larynges of the subjects were found to be normal except for some individuals with slight glottal edema and irritation, which correlated with smoking.

Data collection of acoustic material

To collect the acoustic speech material, telephone conversations by the CSA were recorded four times during a working day: in the morning, before the lunch break, after the lunch break, and at the end of the working day. The recordings were made using a condenser microphone (AKG CK97-0 with AKG SE 300 B amplifier; AKG Acoustics, Vienna, Austria) and a DAT recorder (Sony TDC-D3; Sony Corporation, Tokyo, Japan) at the working place. The microphone was attached to the headset mouthpiece of the phone at approximately 3 cm from the mouth. A sinusoidal of 1 kHz at 82 dB SPL was recorded for calibration. Each recording of the telephone conversations lasted 20 minutes.

Acoustic analyses

A 5-minute excerpt of each 20-minute sample was analyzed using a computer-based analysis program *Puhetauko*.[36,37] The program was developed to handle large amounts of data from continuous speech while minimizing the amount of user-intervention required. Only those sections which were distorted by severe occasional background noise, for example a door slam, were removed manually by means of an editing program. The program classifies the excerpt semiautomatically into segments of voiced and unvoiced speech. The following parameters were studied: F_0, SPL, and AR as well as the number of vocal fold vibrations (Index = $F_0 \times$ voiced speech time).

Inverse filtering

IF was first presented by Miller in the late 1950s as a method to estimate the excitation of voiced speech, the glottal flow.[41] The first phase in IF is the formation of a model for the vocal tract transfer function. The effect of the vocal tract resonance is then canceled from the produced speech waveform by filtering it through the inverse of the model. The result is an estimate of the glottal flow, represented as a time domain waveform.

The semiautomatic IF method used in this study was the Iterative Adaptive IF (IAIF) method.[42] The method consists of two stages: first, a preliminary estimate of the glottal flow is computed. A low-order all-pole filter is then fitted to this rough estimate of the voice source to model the contribution of the glottal flow in the speech spectrum. An estimate of the vocal tract is then obtained by canceling the estimated glottal contribution and the effect of lip radiation. To improve the estimation of formant frequencies for high-pitch voices, the IAIF method models the vocal tract by using an effective technique, discrete all-pole modeling,[43] instead of the widely used conventional linear prediction. The IAIF method consists of two attributes that the user can affect: the order of the vocal tract model and the position of the zero of the first order Finite Impulse Response (FIR) filter that is used to model the lip radiation effect. The user adjusts these quantities until the estimated outcome of the glottal flow shows a maximally long and ripple-free closed phase (Figure 1). These criteria are commonly used in studies within the field.[44,45]

From the speech data, the word /asiakaspalvelu/ (customer-service) taken from the standard phrase, used every time when answering the phone, was

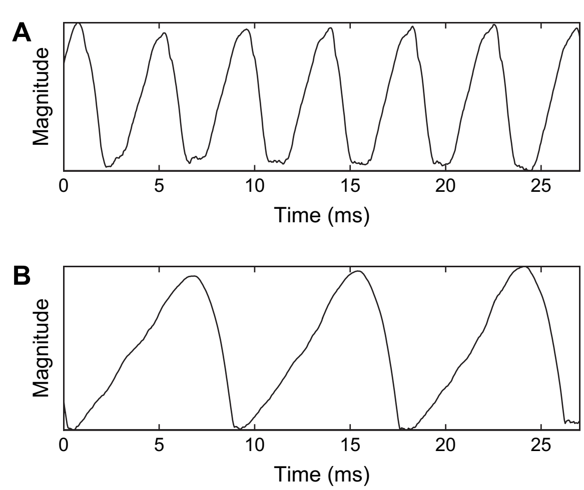

FIGURE 1. Inverse filtered glottal pulses from a female (**A**) and a male (**B**) subject. The user has adjusted the two parameters of the IF technique (for details see ref. 75) to produce a waveform with a maximally long and ripple-free closed phase.

subjected to further analysis. The last vowel /a/ of the word was inverse filtered to estimate the glottal flow. IF was computed over a time window that spanned at least six glottal cycles. The estimated flows were quantified with three glottal source parameters: AQ, NAQ,[38] and H1H2.[39] AQ quantifies time domain characteristics of the glottal pulse during its most important segment, the glottal closing phase. By altering the characteristics of the glottal closing phase the speaker can affect several issues in speech communication, for example, vocal intensity, voice quality, and phonation type. AQ is defined as the ratio between the peak-to-peak amplitude of the flow pulse and the negative peak amplitude of the differentiated flow glottogram. NAQ is calculated from AQ by dividing it by the length of the fundamental period. H1H2 quantifies the spectral tilt of the glottal source by measuring the level difference between the first and the second harmonic.

Data collection of subjective voice complaints

The subjects completed a questionnaire about how they personally experienced their voices at four different times of the day. The questionnaire was completed at the same times the recordings of the speech samples were made: at the beginning of a working day, before the lunch break, after the lunch break, and at the end of the working day. The questionnaire consisted of 12 questions on vocal symptoms as listed below. Similar, symptom-based questionnaires are widely used within the field of occupational voice research.[46–49]

(1) My voice is overstrained.
(2) My voice is hoarse or husky.
(3) I have the feeling of a lump in my throat.
(4) I feel as if I have a choker around my neck.
(5) I have a feeling of mucus in my throat and/or I need to clear my throat frequently.
(6) My throat is dry and/or itchy.
(7) My voice is weak/my voice doesn't resonate.
(8) My voice is tense or I feel I must make an effort when speaking.
(9) My voice is creaky.
(10) My voice often breaks when I speak.
(11) I feel short of breath/I need to gasp for air.
(12) My voice gets worse during the day.

Question no. 12 was answered simply by ''yes'' or ''no,'' while the other 11 questions were answered using the Visual Analog Scale (VAS)[50] with the range ''no symptoms like this'' to ''a lot of symptoms like this''. The VAS is a commonly used instrument for assessing a subjective characteristic or attitude that is believed to range across a continuum of values and, therefore, not recommended to be measured on a discrete scale. From the subject's perspective this approach appears continuous—for example, self-experienced symptoms do not make discrete jumps, as a categorization into none, mild, moderate, and severe would suggest.[51] In this study, the line was 7.5 cm long. Each of the four times of the day was marked on the same VAS-line each time the questionnaire was filled in.

On the basis of the literature on the hazards experienced by voice workers,[49,52–55] voice fatigue and hoarseness were chosen to represent vocal working ability (or its impairment). A general sum-variable was also analyzed. This sum-variable covers symptoms from no. 1 to 11 by summing the VAS estimates for each time of day.

Statistical analyses

A repeated-measures analysis of variance (ANOVA) was used to analyze if there were any statistically significant changes in objective or subjective measures at different times of the day. This analysis was carried out using a repeated-measures analysis of an *SPSS* statistical software package (*Statistical Package for the Social Sciences, Version 13.0* for Windows, SPSS, Chicago, IL). Time of day with four instances was the within-subject variable for each subjective and objective measures, and gender was the between-subject variable. All tests were also run separately for females and males. The analysis also included pair-wise comparisons with the Bonferroni adjustment. For both genders, a Spearman's correlation was calculated for each objective-subjective pair and a Pearson's correlation between the times ''at the beginning of the working day'' and ''at the end of the working day.''

The data contained four measurements of each parameter, but the third measurements of all objective parameters were missing for one male speaker. The missing data values were filled by averaging the corresponding measurements from the second and fourth times of the day.

RESULTS

Due to a considerably smaller number of male subjects compared to that of females, the data of the two genders were analyzed separately. This choice also was justified by the fact that the present study comprises several acoustic measures, such as F_0 and AQ, which are directly reflected by the anatomical size of vocal folds, and consequently, these values will diverge greatly in the two genders. Females are also known to have more voice problems.[4,56,57] Moreover, an additional between-subjects test was conducted to analyze gender differences. This result indicated that all the parameters revealed statistically significant differences between females and males with the exception of SPL, AR, and vocal fatigue.

In the present chapter, the times of data collection will be referred to with the following numbers: 1 = at the beginning of the working day, 2 = before the lunch break, 3 = after the lunch break, and 4 = at the end of the working day.

Objective acoustic parameters during working day

The results from the objective acoustic analyses for both females and males are shown in Table 2. The results of ANOVA revealed that the only parameter which changed significantly for both genders within the working day was F_0. Time of day did not have a statistically significant effect on any other objective parameters, as shown in Table 3. The *post hoc* test showed that for females F_0 increased significantly between times 1 and 4 ($P = 0.014$) and between times 2 and 4 ($P = 0.023$). For males, there was a statistically significant increase between times 1 and 2 ($P = 0.026$) and between times 1 and 4 ($P = 0.049$). These results are presented in detail in Table 6.

Subjective symptoms during working day

The subjective symptoms experienced during the working day are presented in Table 4 for both genders. The results of ANOVA (Table 5) revealed that time of day had a statistically significant effect on all three subjective measures for females (fatigue, $P = 0.002$; hoarseness, $P = 0.002$; and sum-variable, $P = 0.000$). For males, only hoarseness increased significantly ($P = 0.015$). The detailed results from the Bonferroni *post hoc* test are presented in Table 6. For females, the level of vocal fatigue is significantly higher at each time of the day compared to the beginning of the working day (between times 1 and 2, $P = 0.016$; between times 1 and 3, $P = 0.007$; and between times 1 and 4, $P = 0.011$). In hoarseness, there was a statistically significant change between times 1 and 3 ($P = 0.012$) and between times 1 and 4 ($P = 0.007$). The sum-variable changes significantly in all times except between times 3 and 4. For males, there was a statistically significant change only in the value of hoarseness: between times 2 and 4 ($P = 0.027$) and between times 3 and 4 ($P = 0.007$).

Correlation between objective acoustic parameters and subjective voice complaints

Pearson's correlation was computed between changes in complaints by taking into account only the first and last times of the day (times 1 and 4). This was done because in the field of occupational voice care the major interest is typically devoted to effects caused by the entire working day. However, Pearson's correlation between the first and the fourth times were found to be insignificant for both genders.

Perceptual analysis

An informal small listening test was run with voice samples of 15 female speakers to get tentative information about perceptual changes of speech samples. The listeners were three voice experts from the Department of Speech Communication and Voice Research at the University of Tampere, Finland. Samples with duration of 5 minutes were taken from all four times of day and the sample order was randomized for each speaker. The experts rated overall voice quality, roughness, pressedness, and fatigueness with a VAS the length of which was 10 cm. The better the voice quality judged, the lower the value of VAS. As the number of expert listeners was small, statistical analyses were not possible to run and therefore only the main trends of the results were interpreted visually. When the

TABLE 2. *Mean, Maximum, and Minimum Values for the Objective, Acoustic Measures for Females (n = 24) and Males (n = 8)*

	Time of Day							
	Females				Males			
Parameter	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
F_0 (Hz)								
Mean	185.7	186.0	186.6	189.4	102.4	106.3	108.0	107.1
Max	200.6	196.7	201.5	204.5	114.0	116.9	122.2	113.6
Min	174.8	165.6	166.6	179.0	93.6	94.2	101.1	99.5
SPL (dB)								
Mean	81.2	80.8	81.5	81.8	81.8	80.9	81.9	78.5
Max	91.8	880	87.9	90.8	85.5	87.2	87.00	87.7
Min	74.7	72.2	72.6	73.5	77.8	72.0	74.3	64.2
AR								
Mean	18.9	19.0	18.6	18.7	18.8	18.8	18.4	18.7
Max	23.5	24.2	22.9	24.1	21.5	20.4	20.5	21.5
Min	16.8	15.6	15.1	14.83	16.8	16.7	16.3	16.5
Index								
Mean	14 360	15 395	14 570	15 649	6709	5831	7098	7159
Max	20 070	24 101	20 189	22 525	9423	8152	13 535	9237
Min	7438	8848	8333	9086	4595	3399	3277	5519
AQ								
Mean	0.547	0.538	0.549	0.540	0.859	0.815	0.797	0.945
Max	0.731	0.815	0.744	0.818	1.539	1.479	1.122	1.321
Min	0.350	0.407	0.361	0.377	0.589	0.547	0.596	0.714
NAQ								
Mean	0.127	0.1232	0.128	0.124	0.098	0.103	0.095	0.114
Max	0.184	0.170	0.183	0.182	0.148	0.175	0.123	0.141
Min	0.084	0.073	0.084	0.086	0.066	0.064	0.068	0.087
H1H2								
Mean	12.124	11.422	11.638	11.665	8.451	9.064	8.355	9.901
Max	16.289	16.306	16.542	19.176	13.798	12.760	11.319	13.290
Min	7.981	5.751	7.349	5.804	5.950	5.359	6.124	6.717

Notes: The parameters are F_0, SPL, AR, Index = $F_0 \times$ voiced speech time, AQ, NAQ, and H1H2. The times of the day are (1) at the beginning of the working day, (2) before lunch, (3) after lunch, and (4) at the end of the working day.

mean values from the evaluation was calculated, no clear tendency could be found during the course of the day, that is, the experts did not experience the voice quality to change noticeably at different times of the day. For overall grade and fatigueness, the mean values of VAS, averaged over 15 speakers, were located approximately in the middle of the VAS-line for all four times of the day. For pressedness and roughness, however, the values were somewhat lower. Due to the small number of expert listeners, this test cannot be considered confident and therefore it is not discussed further in the present study.

DISCUSSION

This study addresses how different acoustic parameters reflect effects of vocal loading in a modern working environment. To the best of our knowledge, this study is the first one to analyze voice production in realistic work-related speech communication situations with a wide range of

TABLE 3. *Results From the Univariate Tests of the Repeated-Measures ANOVA for Objective Acoustic Parameters Measuring Any Change in the Parameters During the Working Day*

	Females		Males	
Acoustic Measure	***F***	**Sig.**	***F***	**Sig.**
F_0 (Hz)	3.531	0.019*	3.774	0.026*
SPL (dB)	1.058	0.373	1.302	0.300
AR	1.887	0.140	0.094	0.963
Index	1.443	0.238	0.835	0.490
AQ	0.190	0.903	2.097	0.131
NAQ	0.300	0.825	1.816	0.175
H1H2	0.661	0.579	1.006	0.410

Notes: Degree of freedom was 69 for females and 21 for males. Acoustic measures are F_0, SPL, AR, Index = $F_0 \times$ voiced speech time, AQ, NAQ, and H1H2.
Statistical parameters given are F value (F) and P value (Sig.), where $P \leq 0.05$ indicates statistical significance, shown by an asterisk.

measurement techniques and at multiple times of working day.

The result for both genders was that, among the various objective parameters, only F_0 showed any statistically significant change. In many previous vocal loading studies, F_0 rise during vocal loading has been observed in both laboratory[16,17,19,58] and field conditions.[9,11] In the present study, the F_0 rise was systematic, but so small that it can be assumed that F_0 rise alone does not increase the risk of an occupational voice disorder. There has been debate whether an increase in F_0 during a day is a normal phenomenon. For example, Garret and Healey[59] studied F_0 changes without a special voice load and collected data with reading assignments. In their study, both males ($n = 10$) and females ($n = 10$) showed an increase of F_0 during a day, but only for males the change was statistically significant. Also, a study by Artkoski et al[60] investigated F_0 changes during a day without vocal

TABLE 4. *Mean, Maximum, and Minimum Values for Voice Symptoms "My voice gets fatigued" and "My voice gets hoarse," and for the Sum-variable in Females (n = 24) and Males (n = 8)*

	Time of Day							
	Females				Males			
Parameter	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Fatigue								
Mean	1.0	1.6	1.9	1.9	1.0	1.4	1.3	2.1
Max	5.0	5.0	4.0	4.0	3.8	2.2	1.8	5.1
Min	0.2	0.3	0.5	0.6	0.0	0.5	0.6	0.6
Hoarseness								
Mean	2.3	2.6	3.0	3.2	1.6	1.6	1.4	2.4
Max	5.0	4.8	6.2	5.9	5.3	3.2	2.8	4.5
Min	0.3	0.3	0.3	0.3	0.2	0.7	0.4	1.3
Sum-variable								
Mean	11.6	17.2	22.9	27.0	11.2	13.4	14.5	16.5
Max	48.3	39.9	43.4	63.5	39.2	20.4	22.6	23.6
Min	3.6	5.9	3.5	3.6	2.8	5.3	7.9	10.9

Notes: The sum-variable covers symptoms from numbers 1 to 11 (see Data collection of subjective voice complaints) by summing the VAS estimates of each time of day. The times of the day are (1) at the beginning of the working day, (2) before lunch, (3) after lunch, and (4) at the end of the working day. The maximum value for "vocal fatigue" and "hoarseness" is 7.5 and for sum-variable 82.5.

TABLE 5. *Results from the Univariate Tests of the Repeated-Measures ANOVA for Subjective Parameters*

Symptom	Females		Males	
	F	**Sig.**	***F***	**Sig.**
Vocal fatigue	6.868	0.002*	2.152	0.124
Hoarseness	6.902	0.002*	4.433	0.015*
Sum-variable	33.518	0.000*	1.407	0.269

Notes: Degree of freedom (df) was 69 for females and 21 for males. The sum-variable covers symptoms from numbers 1 to 11 (see Data collection of subjective voice complaints) by summing the VAS estimates of each of the four times of the working day. Statistical parameters given are df, F value (F), and P value (Sig.), where $P \leq 0.05$ indicates statistical significance, shown by an asterisk.

loading in 11 females and 10 male subjects. The results showed that F_0 was higher in both groups in the afternoon, but the change during the day was insignificant. There has also been debate on intrasubject variability of F_0. For example, Bourgh et al[61] studied voice samples of 14 subjects, recorded on 15 different days. It was found that F_0 was highly consistent between the different

TABLE 6. *Results from the Bonferroni post hoc Test for Those Objective and Subjective Parameters Which Showed Statistically Significant Changes*

Symptom	Time of Day (*I*)	Time of Day (*J*)	Females		Males	
			Mean Difference ($I - J$)	**Sig.**	**Mean Difference ($I - J$)**	**Sig.**
F_0 (Hz)	1	2	−0.318	1.000	−4.063	0.026*
		3	−0.841	1.000	−6.523	0.135
		4	−3.648	0.014*	−4.749	0.049*
	2	3	−0.523	1.000	−2.460	1.000
		4	−3.330	0.023*	−0.686	1.000
	3	4	2.807	0.446	1.774	1.000
Vocal fatigue	1	2	−0.592	0.016*	−0.363	1.000
		3	−0.833	0.007*	−0.250	1.000
		4	−0.900	0.011*	−1.025	0.052
	2	3	−0.242	1.000	0.113	1.000
		4	−0.308	1.000	−0.663	1.000
	3	4	−0.067	1.000	−0.775	1.000
Hoarseness	1	2	−0.325	0.621	−0.050	1.000
		3	−0.683	0.012*	0.238	1.000
		4	−0.867	0.007*	−0.825	0.329
	2	3	−0.358	1.000	0.288	1.000
		4	−0.542	0.093	−0.775	0.027*
	3	4	−0.183	1.000	−1.063	0.007*
Sum-variable	1	2	−5.579	0.002*	−2.200	1.000
		3	−11.208	0.000*	−3.275	1.000
		4	−15.400	0.000*	−5.288	0.899
	2	3	−5.629	0.000*	−1.075	1.000
		4	−9.821	0.000*	−3.088	1.000
	3	4	−4.192	0.142	−2.013	1.000

Notes: Time of day is the within-subject variable: (1) at the beginning of the working day, (2) before lunch, (3) after lunch, and (4) at the end of the working day. The sum-variable covers symptoms from numbers 1 to 11 (see Data collection of subjective voice complaints) by summing the VAS estimates of each of the four times of day.
Column Sig. represents P values, where $P \leq 0.05$ indicates statistical significance, shown by an asterisk.

recording sessions. In addition, standard deviation of F_0 has been used in research of intonation.[62] In the field of occupational voice research, Rantala et al,[7,24] for example, analyzed voice production of teachers by recording three samples from a single lecture. To study voice loading, this was repeated at the first and last lectures of the teacher's working day. It was found that F_0, averaged over three recording sessions, was higher in the afternoon lecture than in the morning.

In the present study, F_0 and SPL levels of the CSA were much lower than those reported for teachers.[9] The main reason for this is obvious: the background noise level was low despite the fact that the working space was an open-plan office. According to a workplace hygiene survey conducted by the Oulu Regional Institute of Occupational Health, the SPL of CSA's speech corresponds approximately to 55 dB at 0.5 m, ie, to a normal or even a soft speaking voice. The findings of the phoniatric examination also indicate that the vocal loading on the subjects could not cause organic changes. However, it should be observed that acoustic conditions are not the only issues effecting to eventual voice changes in professional speakers. A review by Mattiske et al,[63] dealing with causes of vocal problems in teachers, addresses several other factors, such as lack of vocal education and training, unfavorable voicing strategies, and those related to individual's emotional stage.

The present study used IF to gain knowledge of the functioning of the vocal folds as reflected by the glottal flow parameters. IF was based solely on speech pressure signals captured from a free field by a microphone. In contrast to this, a considerable number of the previous IF studies have used flow recordings.[39,64–68] The oral flow signal is recorded with a pneumotachograph mask, also known as Rothenberg's mask.[44] Studies by Hillman et al[66] and Holmberg et al[64] argue that the flow mask offers a noninvasive possibility to measure airflow. However, especially considering occupational real-environment voice research, the mask limits and, moreover, might also confine the subject's natural way of phonation. A study by Orr et al[69] compared IF from flow signals, measured with a Rothenberg's mask and microphone signals. The comparison indicated that the two measurement techniques gave different estimates for the glottal source. The results might be explained by a number of reasons, such as the subjects' inconsistent voicing strategies, a large within-speaker variation, and the acoustic effects of the flow mask. If voice measurements are to become a routine part of occupational voice research, the psychological effect of the mask should be taken into consideration as well. Therefore, free field microphone recordings, as performed both in the present study and in certain previous works on vocal loading,[19,20,70] are more suitable in allowing a fully noninvasive approach to capture voice production during a working day. However, this requires the use of high-quality equipment (eg, the choice of microphone and amplifiers) and reliable recording conditions (eg, control of background noise and microphone distance).

There are a few previous studies in which vocal loading is investigated by IF but all these studies have been performed in laboratory settings.[19,20,70] In contrast to this, the present investigation is the first one to estimate the glottal flow from continuous speech produced in a natural communication situation for the purpose of occupational voice research. The vowel analyzed was taken from a standard phrase used every time the CSA answered the phone. This approach is different from the widely used practice in which analysis is computed on isolated words, specially selected for IF (usually the word /pa:p:a/).[19,58] In spite of the fact that continuous speech provides challenging material for IF, this study demonstrated that such voice data are possible to use in occupational voice research. This naturally called for manual adjustments of IF parameters, for example, positioning the analysis frame to cover only the vowel segment. For most of the speech samples analyzed, the obtained estimates of the glottal flow showed a waveform typically reported in laboratory experiments of IF analysis (see examples in Figure 1): a flat closed phase is first followed by a gradual glottal opening which is then followed by a steeper closing phase. Even though the estimation of the glottal flow was conducted successfully, the glottal flow parameters did not show statistically significant changes during the working day. One reason for this might be that all the subjects were relatively young and their mean working experience in telephone was less that 1 year. Furthermore, the background noise level in the CSA's office was lower than the working environment of teachers in kindergartens and elementary schools,[10] who are known to be the group of employees with the most voice problems.[1,2,49,53,71] However, it should be noted that especially teaching involves challenging speech communication situations[72,73] and therefore teachers' voice fatigueness does not have to be solely due to environmental factors.

The present study also analyzed whether any of the objective measures would correlate with work-related subjective vocal symptoms reported by the participants. Within the field of voice research understanding correlations between subjective and objective measures would give valuable insight into physiological and acoustical reasons behind voice symptoms. In addition, these relations would be of great value in assessing effects and quality of voice therapy and training. The results of the present study showed that all three voice symptoms (vocal fatigue, hoarseness, and sum-variable) yielded a statistically significant increase during the working day in females, while hoarseness reached a statistically significant increase in males. However, the correlation between the first and last times of the working day did not show a significant result. In occupational voice research, there are a few similar previous studies.[6,7,35,74] These studies have not yet reached unanimous conclusions. In the studies by Ma and Yiu[6] and Laukkanen et al,[74] the self-perceived voice problem did not correlate with the degree of voice-quality impairment measured acoustically. However, the studies by Rantala et al[8] and Rantala and Vilkman[35] showed a tendency toward a relationship between subjective complaints and objective acoustic measures of voice. Self-perceived symptoms and objective acoustic measurements were also linked in a recent study by Jonsdottir et al.[11] They studied female teachers' voices during a working day with and without electric sound amplifier. Although F_0 has been claimed to rise as a consequence of extensive voice use,[9,17–19,55] Jonsdottir et al.[11] found that F_0 and SPL increased more when amplification was used. This occurred despite the fact that with a sound amplifier a teacher is able to use natural F_0 and intensity. Additionally, the subjects' self-reported voice complaints suggested less vocal fatigue when amplification was used. This supports the argument that a vocal loading–related increase in F_0 and SPL as such is not always a sign of vocal fatigue.

To conclude, the goals of this study were to investigate occupational voice loading with a wide range of acoustic measurement techniques in realistic working situations in the course of a working day, and to investigate if these objective parameters correlate with subjective voice complaints. It was found that only F_0 reached a statistically significant change during the working day. No correlations between objective and subjective measurements were found. Noninvasive measurement of glottal activity in realistic work environments is not possible with any technique other than IF based on pressure signal. The present study achieved encouraging results in showing that a semiautomatic IF method gives reliable estimates of the glottal flow for this purpose. However, a vowel inverse filtered from a short standard phrase, as conducted in the present study, does not supply sufficient speech data to measure vocal loading during an entire working day; a standard phrase at the beginning of a phone call is easy to control even if the voice would otherwise be fatigued. Hence, to be able to apply IF in occupational voice research, there is a need to develop methods with which it would be possible to detect from continuous speech those segments that are known to be most accurate for IF, that is, nonnasalized vowels with high first formant, and to run analyses on all these segments. This kind of approach could be implemented by combining speech recognition techniques to glottal IF. All in all, the results from the present study encourage researchers within the field of occupational voice care to apply versatile measurement techniques in studying occupational voice loading.

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