Acoustic Measures and Self-reports of Vocal Fatigue by Female Teachers

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Summary: This study investigated the relation of symptoms of vocal fatigue to acoustic variables reflecting type of voice production and the effects of vocal loading. Seventy-nine female primary school teachers volunteered as subjects. Before and after a working day, (1) a 1-minute text reading sample was recorded at habitual loudness and loudly (as in large classroom), (2) a prolonged phonation on [a:] was recorded at habitual speaking pitch and loudness, and (3) a questionnaire about voice quality, ease, or difficulty of phonation and tiredness of throat was completed. The samples were analyzed for average fundamental frequency (F0), sound pressure level (SPL), and phonation type reflecting alpha ratio (SPL [1–5 kHz]/SPL [50 Hz–1 kHz]). The vowel samples were additionally analyzed for perturbation (jitter and shimmer). After a working day, F0, SPL, and alpha ratio were higher, jitter and shimmer values were lower, and more tiredness of throat was reported. The average levels of the acoustic parameters did not correlate with the symptoms. Increase in jitter and mean F0 in loud reading correlated with tiredness of throat. The results seem to suggest that, at least among experienced vocal professionals, voice production type had little relevance from the point of view of vocal fatigue reported. Differences in the acoustic parameters after a vocally loading working day mainly seem to reflect increased muscle activity as a consequence of vocal loading.

Key Words: Vocal loading—Symptoms—Phonation type—F0—SPL—Spectrum—Jitter—Shimmer.

INTRODUCTION

Voice problems are known to be common among voice professionals worldwide. Teachers form a large group of voice professionals,1,2 and their voice problems have been focused on in many studies.3–8 The issue is also important from the point of view of pupils and students, because a well-functioning voice is a tool of communication and, thus, contributes to the listeners’ ability to follow the instruction in classroom. Most studies have concerned female teachers, because females are a majority in the teaching profession and females
also are known to have about twice as many voice problems as males. There is evidence suggesting that teachers’ voice problems are related to vocal loading at work. For instance, studies have shown that teachers speak more and with a higher sound pressure level (SPL) compared, for example, to nurses and that teachers also present with more voice problems than do nurses.9–11 Furthermore, teachers do not have voice complaints during vacation time but during the term.11–12 Various acoustic changes have been found to take place after a vocally loading task, whether it is a loading test in a laboratory or a teacher’s working day or an actor’s theater performance.13–18 Fundamental frequency (F0) and SPL have been found to be higher after loading, and the spectral tilt has also been found to be lower in females after loading. The results of some studies suggest that there is a relation between voice production type and the amount of voice complaints. Those subjects who had higher mean F0 and SPL in a loading test reported more symptoms of vocal fatigue after the test.19 Likewise, those (female) teachers who used higher F0 and SPL in their classroom speech, had more voice complaints than their colleagues.20 The amount of changes in the acoustic parameters due to vocal loading has also been reported to differentiate between subjects with more voice complaints and those with few or no complaints at all: Teachers with few complaints showed higher F0 and SPL increase and their spectral tilt diminished more.20 Interestingly, these findings seem to suggest a change toward a more hyperfunctional voice production.

This study investigates in a larger number of subjects the relations between symptoms of vocal fatigue and voice production type as reflected in the acoustic parameters of speech, and changes in acoustic speech parameters during loading. Female teachers are focused on for the reasons given above.

MATERIALS AND METHODS

Subjects
Seventy-nine Finnish female primary school teachers volunteered as subjects of the study. The subjects were recruited by a questionnaire on the Internet after permission for this investigation had been given by the local school administration. The questionnaire collected background information like age, teaching experience, size of classroom, voice training, general health (allergies, reflux, etc), living habits (eg, smoking), etc. The mean age of the subjects was 41.1 years (range 26–57 years), and most of them had considerable teaching experience (mean 15 years, range 1–32 years). Most of the subjects (N = 51) were non-smokers; 18 were smokers, and 10 did not provide this information. All subjects were functionally healthy voice professionals in the sense that they regarded themselves as fully capable of their vocally demanding profession.

At the beginning of the term, prior to any recordings for the study, the subjects went through a phoniatric inspection (laryngeal mirror). Field conditions did not allow for any more accurate inspection methods and other policy would have reduced the number of participants in the study. According to this inspection, 44 subjects were (phoniatrically) healthy, that is, there were no organic lesions visible in their vocal folds and 35 showed mild pathological changes (like slight redness of the vocal fold surface). (Out of the original sample of 90 subjects, 11 were classified as phoniatrically sick, ie, with nodules, polyps, etc, and were excluded from further analyses). According to the voice quality assessment during phoniatric examination, 4 subjects were classified as having major hoarseness, 57 had no hoarseness at all, and 18 had obvious but not severe hoarseness. According to the evaluation by the authors during acoustic analyses of the material, the subjects sounded as having an “ordinary teacher’s voice,” that is, slightly “worn” but rather well functioning (sufficient projecting capacity, dynamic range, and endurance, ie, no obvious deterioration perceivable after a working day).

Tasks and Recordings
The subjects were recorded before (at about 7:30 AM) and after (at about 4 PM) a vocally loading working day. Recordings were made using a portable digital recorder (Sony TCD-D8; Sony Corporation, Tokyo, Japan) and a microphone (AKG B29L; AKG, Vienna, Austria) attached to a headset. The microphone was placed at a distance of 6 cm from the corner of the subject’s mouth. The recordings were calibrated for SPL measurements using
a sound generator (BOSS TU-120; Roland Corporation, Los Angeles, CA) and a sound level meter (Brüel & Kjær 2206; Espoo, Finland). The subjects read aloud a prose extract of about 1-minute duration in Finnish (1) at habitual conversational loudness and (2) loudly, corresponding to speech in a large, noisy classroom. They also sustained the vowel [a:] for about 5 seconds at habitual speaking pitch and loudness. The text reading samples did not contain s-phonemes, and the Finnish language does not contain aspirated plosives. Due to the short mouth-to-microphone distance, the signal-to-noise ratio was also well above 30 dB. These facts are important when drawing conclusions of phonation type on the basis of acoustic voice analysis results, for example, alpha ratio. Before and after the working day, the subjects also completed a questionnaire concerning symptoms of vocal fatigue. In the questionnaire, a 200-mm visual analogical scale (VAS) was used to mark ease or difficulty of phonation and voice quality to enable the possible warm-up effects to be reported. (Voice production: 0 = particularly easy, 100 mm = ordinary, 200 mm = very difficult. Voice quality: 0 = very good, 100 mm = ordinary, 200 mm = very poor.) In the evaluation of tiredness of throat a 100-mm scale was used (0 = no tiredness at all, 100 mm = lots of tiredness).

The recording and questionnaire completion procedure was conducted at the beginning of the autumn term (September).

Analyses

The text reading samples were analyzed for mean F0 and SPL, and alpha ratio was calculated by subtracting the SPL of the range 1–5 kHz from that of the range 50 Hz–1 kHz. Alpha ratio, describing the average sound energy distribution along the frequency range (spectral tilt), reflects phonation type, when signal-to-noise ratio has been taken into account. Hypofunctional voice production and soft phonation are typically characterized by a small alpha ratio, whereas alpha ratio is relatively large in hyperfunctional and loud voice production. Alpha ratio has been found to change significantly during a vocally loading working day.

Vowel samples were analyzed for F0, SPL, and period-to-period perturbation in period length (jitter) and amplitude (shimmer). A large amount of perturbation is related to hoarse voice. A reduced amount of perturbation may be related to higher F0 and SPL and reflect higher muscle activity. The analyses were performed using a signal analysis system named Intelligent Speech Analyser, developed by Raimo Toivonen, M.Sc., Eng.

Statistical analyses were carried out using SPSS-11 software (SPSS Inc., Chicago, IL). Student’s t test or Wilcoxon Signed Rank Test was used to study the significance of differences between parameter values obtained before and after the working day. A parametric test (Student’s t test) was used for those variables that showed a normal distribution (skewness between -1 and +1). Differences between subject groups (healthy and almost healthy, and smokers vs nonsmokers) were studied using Student’s (independent samples) t test or Mann–Whitney U test. Relations between acoustic parameters and subjective evaluations of voice production, voice quality, and tiredness of throat were studied with Pearson or Spearman correlations (Spearman was used when the variables did not show a normal distribution).

**RESULTS**

Table 1 shows the average results for all 79 subjects. Mean F0, SPL, and alpha ratio increased in text reading at habitual loudness, and F0 and alpha ratio increased in loud reading also. In vowel phonation, both F0 and SPL increased and jitter and shimmer values decreased. More tiredness in the throat was reported after the working day.

The change in alpha ratio correlated with SPL ($r = 0.57$, $P = 0.000$) and in loud reading also with F0 ($r = 0.43$, $P = 0.000$). Jitter and shimmer correlated negatively with F0 and SPL (mean jitter vs F0: $r = -0.33$, $P = 0.003$, mean jitter vs SPL: $r = -0.31$, $P = 0.007$; shimmer vs F0: $r = -0.38$, $P = 0.001$; and shimmer vs SPL: $r = -0.28$, $P = 0.013$).

For the whole group, no correlations were found either between means of acoustic parameters and the symptoms of vocal fatigue or between changes in acoustic parameters and in the symptoms during
a working day. For the healthy subjects (N = 44), an increase in mean jitter correlated with tiredness of throat (r = 0.31, P = 0.046). For the almost healthy (N = 35), tiredness of throat correlated with an increase in F0 of loud reading (r = 0.39, P = 0.026). The almost healthy differed significantly from the healthy by having a higher mean F0 both in habitual and loud text reading (mean F0 in habitual reading: 188.7 Hz, standard deviation [SD] 14.9 Hz for the healthy, and 199.8 Hz, SD 14.5 Hz for the almost healthy. In loud reading, the corresponding values were 205.9 Hz, SD 17.9 Hz and 217.4 Hz, SD 15.6 Hz). The two groups did not differ from each other in terms of the percentage difference between the mean F0 in habitual and loud reading (for the healthy: mean 15.2%, SD 39.5, for the almost healthy: 9.1%, SD 8.2). The percentage difference did not correlate with the vocal symptoms either.

Smokers and nonsmokers did not differ from each other in any parameters studied.

**DISCUSSION**

In this study, F0, SPL, and alpha ratio were used to investigate the voice production type and the possible changes in it (or the state of vocal organ) due to vocal loading at work. These variables were chosen because in earlier studies they have been found to differentiate between subjects with different amount of self-reported vocal fatigue related to vocal loading. It is plausible that these variables

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**TABLE 1.** Mean Values (SDs in Parentheses) for Average F0, SPL, and Alpha Ratio (SPL [1–5 kHz]–SPL [50 Hz–1 kHz]) in Habitual Text Reading and Loud Reading, and for F0, SPL, and F0 and Amplitude Perturbation (Jitter and Shimmer, Respectively) in Vowel Samples Recorded Before and After a Teacher’s Working Day, at the Beginning of the Autumn Term

<table>
<thead>
<tr>
<th></th>
<th>Morning</th>
<th>Afternoon</th>
<th>Significance of Difference, P</th>
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<tbody>
<tr>
<td><strong>Reading</strong></td>
<td></td>
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<tr>
<td>F0 (Hz)</td>
<td>190.8 (16.2)</td>
<td>196.2 (16.6)</td>
<td>0.000</td>
</tr>
<tr>
<td>Difference in (%)</td>
<td>2.7 (5.0)</td>
<td></td>
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</tr>
<tr>
<td>SPL (dB)</td>
<td>76.3 (3.4)</td>
<td>77.1 (4.4)</td>
<td>0.036</td>
</tr>
<tr>
<td>Alpha (dB)</td>
<td>−15.1 (2.7)</td>
<td>−13.4 (3.0)</td>
<td>0.000</td>
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<tr>
<td><strong>Loud reading</strong></td>
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<tr>
<td>F0 (Hz)</td>
<td>208.0 (18.0)</td>
<td>213.8 (19.1)</td>
<td>0.000</td>
</tr>
<tr>
<td>Difference in (%)</td>
<td>2.6 (5.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPL (dB)</td>
<td>83.5 (4.0)</td>
<td>83.8 (4.7)</td>
<td>ns</td>
</tr>
<tr>
<td>Alpha (dB)</td>
<td>−9.5 (3.0)</td>
<td>−8.6 (3.2)</td>
<td>0.000</td>
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<tr>
<td>[a:]</td>
<td></td>
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<tr>
<td>F0 (Hz)</td>
<td>195.4 (26.3)</td>
<td>202.1 (30.1)</td>
<td>0.030</td>
</tr>
<tr>
<td>Difference in (%)</td>
<td>2.6 (5.1)</td>
<td></td>
<td></td>
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<tr>
<td>SPL (dB)</td>
<td>82.9 (5.9)</td>
<td>84.2 (5.3)</td>
<td>0.033</td>
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<tr>
<td>Alpha (dB)</td>
<td>0.60 (0.70)</td>
<td>0.62 (0.90)</td>
<td>ns</td>
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<tr>
<td>Mean jitter (%)</td>
<td>0.12 (0.14)</td>
<td>0.11 (0.15)</td>
<td>0.025</td>
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<tr>
<td>Shimmer (dB)</td>
<td>0.57 (0.28)</td>
<td>0.49 (0.31)</td>
<td>0.018</td>
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<td><strong>Subjective evaluations</strong></td>
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<tr>
<td>Phonation (mm, using VAS)</td>
<td>88.4 (35.7)</td>
<td>92.6 (37.0)</td>
<td>ns</td>
</tr>
<tr>
<td>Throat (mm, using VAS)</td>
<td>35.6 (18.5)</td>
<td>45.9 (20.2)</td>
<td>0.000</td>
</tr>
<tr>
<td>Voice (mm, using VAS)</td>
<td>98.1 (34.2)</td>
<td>97.6 (34.7)</td>
<td>ns</td>
</tr>
</tbody>
</table>

Additionally, mean values and SD for self-evaluated difficulty of voice production (“phonation”), tiredness of throat (“throat”), and voice quality (“voice”) reported before and after a working day using a VAS (mm). 0 = particularly easy voice production, 100 = ordinary voice production, 200 = very difficult voice production. Tiredness of throat: 0 = no tiredness at all, 100 = very tired; voice quality: 0 = very good, 100 = ordinary quality, 200 = very poor quality. Significance of difference (Student’s Paired t test or Wilcoxon Signed Rank test), ns = nonsignificant (P > 0.05).
may reflect vocal effort. Higher F0 and SPL and tighter adduction also increase the amount of mechanical loading (in terms of impact stress) posed on the vocal fold tissue during voice production.\textsuperscript{28} Alpha ratio may reflect the amount of adduction.

The results of this study suggest that at least for such a group of experienced, functionally healthy voice professionals, voice production type does not correlate with symptoms of vocal fatigue. It is known that acoustic and perceptual voice quality does not have a clear relation to vocal fold pathologies. On the other hand, previous studies have suggested that acoustic variables and vocal loading-related changes in them would differentiate between subjects with varying amounts of symptoms of vocal fatigue.\textsuperscript{17,19,20} It is possible, however, that instead of voice production type as such, vocal fatigue is more related to other things, for instance, the particular amount of speech during a working day or the amount of voice respite during the day. Individual differences in the endurance of the tissue and the rate of the tissue healing processes may also be important. However, it may not be possible to reliably estimate the type of voice production in classroom speech by analyzing text reading, even though loud reading was also used to correspond to loud speech in the classroom. Furthermore, better discrimination might be achieved by measuring not only the absolute arithmetic mean or mode of F0 and SPL but those values in relation to each individual’s range. The results obtained by Mäki et al\textsuperscript{19} suggest this. However, in a screening test for a large number of subjects this would not have been possible in practice because it would have required time-consuming extra testing like measurement of the lowest possible tone and the highest possible SPL in shouting.

Higher F0, SPL, and alpha ratio values were measured after the working day. This is in line with earlier results of vocal loading.\textsuperscript{13–18} However, unlike the results of Rantala et al\textsuperscript{17} and Rantala and Vilkman,\textsuperscript{20} the magnitude of these changes did not correlate negatively with symptoms of vocal fatigue. Instead, the increase in F0 of loud reading correlated positively with tiredness of throat in the subjects with mild changes of the vocal folds (“the almost healthy”). It is noteworthy, that a shortcoming in the studies mentioned\textsuperscript{17,20} was that data of the subjective voice complaints were not collected at the same time as the recordings, but were general self-evaluation of the subjects. The number of subjects was also relatively small (10–33). Increase in F0, SPL, and alpha ratio as well as decreased perturbation values may reflect increased activity in the voice production muscles. This seems to be a normal result of adaptation to loading. Higher F0 and SPL—that is greater activity in the laryngeal muscles—tend to decrease the amount of perturbation.\textsuperscript{26,27} Lower perturbation values seem to reflect themselves a higher muscle tonus and somewhat more hyperfunctional voice production. In this study, an increase in jitter correlated with tiredness of throat in the healthy. This might result from lowered muscle tonus and impaired neuro-motor control of the larynx due to fatigue. Loading-related swelling of the vocal fold tissue could also increase vocal perturbation.

The almost healthy differed from the healthy in having a higher mean F0 both in habitual and loud reading. A higher F0 is likely to imply a higher mechanical load posed on the vocal folds. It is tempting to speculate whether the use of higher F0 also contributes to the mild pathological changes in the vocal folds. A larger increase in the mean F0 of loud reading also correlated with tiredness of throat in the almost healthy. Raising F0 may be used to compensate for loading changes of the vocal fold tissue. It is also possible that when the starting point already is higher, a further increase in F0 (and, thus, in loading) begins to cause more symptoms of vocal fatigue.

Naturally, one problem related to self-evaluation is that true comparison between subjects is at least theoretically difficult, because it is possible that individual sensitivity to various symptoms of vocal fatigue varies considerably. In this study, for instance, the healthy and almost healthy did not differ from each other in the amount of symptoms reported. It can be speculated whether this means that the amount of objective organic fatigue did not differ between the groups or whether it indicates less sensitivity in the phoniatrically almost healthy. In the latter case, it could be hypothesized further that less sensitivity to negative tissue changes and voice alterations is one of the reasons for some mild pathological changes in the vocal fold tissue.

It is open to speculation whether the results have been affected by the self-choice of subjects. It is
possible that the subjects with either no vocal problems at all or with the most severe voice problems did not participate. On the other hand, the focus was on functionally healthy teachers whose vocal well-being might be improved with certain interventions. (The material was originally collected for studying the effects of voice hygienic lectures, voice training, and voice massage treatment on teachers’ vocal well-being at work.) According to self-reports, laryngoscopic examination and voice quality assessment made by the phoniatrician, the subjects showed a clear variation, which seems to allow reasonable comparisons.

CONCLUSION

In functionally healthy, experienced female voice professionals (teachers)

1. Voice production type is apparently not related to symptoms of vocal fatigue.
2. Higher F0, SPL, and alpha ratio and lower jitter and shimmer values after a working day mainly seem to reflect increased muscle tonus as an adaptation to loading. Naturally, a physiological study would be required to draw decisive conclusions of changes in muscle activity.
3. Increase in jitter correlated with tiredness of throat, possibly reflecting muscle fatigue or swelling of the vocal fold tissue.
4. Increase in F0 of loud reading correlated with tiredness of throat.
5. The main difference between phoniatrically healthy and almost healthy was a higher F0 in the latter (a reason for the mild changes of the vocal fold tissue?).
6. It remains a challenge to find an informative, reliable, and practical set of variables for objective screening of vocal loading.

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