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Cepstral and Perceptual Investigations in Female Teachers with Functionally Healthy Voice

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ABSTRACT

Purpose:
The present study aimed at measuring the smoothed and non-smoothed cepstral peak prominence (CPPS and CPP) in teachers who considered themselves to have normal voice but some of them had laryngeal pathology. The changes of CPP, CPPS, sound pressure level (SPL) and perceptual ratings with different voice tasks were investigated and the influence of vocal pathology on these measures was studied.

Method: Eighty four Finnish female primary school teachers volunteered as participants. Laryngoscopically, 52.4 % of these had laryngeal changes (39.3 % mild, 13.1 % disordered). Sound recordings were made for phonations of comfortable sustained vowel, comfortable speech and speech produced at increased loudness levels as used during teaching. CPP, CPPS and SPL values were extracted using *Praat* software for all three voice samples. Sound samples were also perceptually evaluated by five voice experts for overall voice quality (10 point scale from poor to excellent) and vocal firmness (10 point scale from breathy to pressed, with normal in the middle).

Results: The CPP, CPPS and SPL values were significantly higher for vowels than for comfortable speech and for loud speech compared to comfortable speech ($p<0.001$). The loud speech was perceived to be firmer and have a better voice quality than comfortable speech. No significant relationships of the laryngeal status with cepstral values, perceptual ratings or voice SPLs were found ($p>0.05$).

Conclusion: Neither cepstral measures nor perceptual evaluations could clearly distinguish teachers with laryngeal changes from laryngeally healthy teachers. Considering no vocal complaints of the subjects, the data could be considered representative of teachers with functionally healthy voice.

Key words: Teachers' voice, Voice SPL, CPP, CPPS, Perceptual evaluation, laryngeal pathologies

1. INTRODUCTION

Cepstral Peak Prominence (CPP) and the Smoothed Cepstral Peak Prominence (CPPS)[1, 2] are considered to be rather robust acoustic measures of overall severity of dysphonia.[3, 4] CPP is a measure of the relative cepstral peak amplitude (in decibels) of the voice signal.[1, 2] It is obtained by finding out the difference between the maximum cepstral peak value occurring within the boundaries of the expected phonational quefrencies and the corresponding value on the regression line fitted on the cepstrum. CPP was originally developed to analyze sustained vowels and measures the degree of harmonic organization (periodicity) of the signal over the "noisiness" in the voice signal. The Smoothed Cepstral Peak Prominence (CPPS) is a modification of the CPP measure, where the individual cepstra are smoothed across time and quefrency domains, which was developed for greater prediction accuracy particularly in speech signals.[2] The CPP and CPPS measures were shown to be more reliable than the traditional perturbation measures such as jitter, shimmer and noise to harmonic ratio (NHR).[5-7] A higher CPP amplitude value can be found in highly periodic signals and lower CPP amplitude value in less periodic or aperiodic signals.[1, 5] From previous clinical studies, CPP and CPPS measures have been found to correlate strongly with perceptual evaluations of voice.[2, 6, 8] Applications of CPP measures have been extended to the analysis of different phonation types. It has been reported that CPP values are higher for pressed and normal (modal) phonation compared to, breathy type of phonations.[9] These findings have been attributed to larger open quotient values of glottal waveform during breathy phonations which lead to increased spectral noise.[9] Wolfe and Martin[10] classified dysphonic patients into breathy, hoarse and strained voice types based on four parameter model including cepstral peak prominence. The CPP values were lower for hoarse and breathy voice compared to strained voice type.[10] Lower CPP values have been reported to differentiate rough from normal voice based on the increased amplitude of noise components in relation to fundamental frequency in rough voice.[11] The CPP measure has also been useful to differentiate hypofunctional from normal voice.[12] Perceptual evaluation of strain severity has as well shown moderate to high correlation with the cepstral measures.[13] CPP and other cepstral based measures have also been reported to be useful in assessing voice quality in various voice disorders,[14] vocal nodules[15] and unilateral vocal fold paralysis.[16] CPPS has been recommended for voice screening purposes as it has a high predictive value for voice disorder status.[17]

CPP as well as CPPS have been used to analyze both sustained vowels and continuous speech samples in assessing dysphonic voices. Hillenbrand and Houde[2] reported that both CPPS and CPP were good predictors of breathiness rating, while CPPS showed slightly better results over CPP for both sustained vowel and continuous speech samples. In a study by Hasanvand et al.[18] CPPS and CPP were shown to be significantly reduced in female dysphonic subjects compared to non-dysphonic subjects for both vowel and speech (reading) samples. Comparing dysphonic to non-dysphonic males, the authors showed that CPPS from vowel and speech and CPP from only speech sample were significantly reduced. Authors advocate use of both CPP and CPPS for differentiating dysphonic and non-dysphonic individuals. In another study, Brinca et al.[19] reported both CPP and CPPS measures to differentiate between dysphonic and normal individuals for sustained vowel sample, but only CPP from continuous speech sample to help differentiate between the two groups.

These authors as well report use of both CPP and CPPS as a promising acoustic measure of dysphonia. Moers et al.[20] reported the reading-based CPP and CPPS to correlate well with perceptual rating of dysphonic voice. Based on all these results we explore in this paper the use of both CPP and CPPS measures for both vowel and speech samples.

Occupational voice users normally demand more attention than non-occupational voice users. CPP measures have been applied to assess voice quality in vocally healthy occupational voice users, such as radio broadcasters[21] and in Indian classical singers.[22] The Indian Carnatic classical singers had a higher CPP compared to nonsingers, attributing it to stronger harmonic organization in the singers. However, in the study on radio broadcasters, there was no difference between the radio performers and non-radio performers on the cepstral measures indicating no differences in the strength of harmonic content in the voice signal between the two groups.

One of the largest groups of professional voice users are teachers. Teacher's voice is vulnerable to disorders as a result of prolonged voice use and heavy vocally loading conditions.[23] Poor environmental[23-26] and working conditions,[27, 28] unawareness of appropriate vocal hygiene[29] and lack of voice training,[30] all may contribute to the development of voice disorders in teachers. Several studies have shown a high prevalence of frequently occurring symptoms of vocal overloading and fatigue in teachers.[27, 30-32] Studies have shown that in presence of unfavorable environmental conditions such as background noise, teachers tend to raise their voice, and speak with increased vocal loudness leading to increased vocal effort and strain in these teachers.[33-35] There have been some indications, that cepstral peak prominence values are influenced by vocal loudness, or more explicitly by sound pressure level (SPL) of voice.[36] This relationship has not yet been well explored and deserves more attention, however.

The present study applies cepstral (CPP and CPPS) and perceptual evaluations to assess voice quality of female primary school teachers who are serving in a vocally loading profession and have not been seeking for help for any voice problems. These teachers considered themselves to have normal voice, but in some of them pathological findings in the larynx were discovered through laryngoscopy, which did not make it impossible for them to work as a teacher. The questions addressed in this study are: (1) What is the perception of the voice quality and firmness for the sustained vowel, comfortable and loud speech in teachers who consider themselves to have normal voice? (2) What are the representative CPP, CPPS and SPL values for sustained vowel, comfortable and loud speech in these teachers? (3) How are these CPP and CPPS values related to the measured voice SPLs? (4) In case of laryngeal pathologies, are these perceivable by voice expert listeners and detectable by the CPP, CPPS and voice SPL measures?

2. MATERIALS AND METHOD

2.1 Participants and their laryngeal status

The material for this study has been derived from an earlier study,[37] which investigated the relationship between self-reported voice symptoms, working conditions, background factors (such as noise and air quality) and phoniatric evaluation but did not attempt using cepstral measures in these teachers. A total of 84 Finnish female primary school teachers volunteered as subjects for the present study. The mean age was 42.6± 8.9 years. The mean years in profession were 16.5±9.4 years. The mean number of teaching hours per week was 31.3±7.3 hours. All the participants considered themselves to be vocally healthy and capable of carrying their profession. Some laryngeal changes were found in 44 (52.4%) teachers; 33 of them (39.3 %) had mild and 11 (13.1 %) had substantial changes that were evaluated by an experienced phoniatrician on a three point scale (1-healthy; 2-mild changes; 3-disorderd). This laryngeal status rating was based on case history and indirect mirror laryngoscopy. Mirror laryngoscopy was used out of practical reasons, since the laryngeal inspections were mostly made in field conditions and no portable rigid endoscopy system was available for that purpose. The mild laryngeal changes consisted of mild vocal fold erythema, arytenoid erythema, mild edema and mild glottal closure insufficiency. The more substantial findings (disordered group) included individuals having nodules, polyps, chronic laryngitis, laryngeal reflux disease, moderate to severe glottal closure insufficiency.[37] **Table 1** lists the laryngeal findings in the study participants diagnosed via indirect laryngoscopy.

Table 1: Diagnostic distribution of study participants.
(Some participants presented with more than one finding)

Laryngeal status Category (No. subjects)	Laryngeal findings	Number of subjects
Healthy (40)	Normal laryngeal findings	40
Mild changes (33)	Mild redness of vocal folds	4
	Mild swelling of VF	5
	Beginning vocal nodule	1
	Mild redness in arytenoids	7
	Slight amount of thick mucus	2
	Slight hoarseness	7
	Incomplete glottal closure in phonation	10
	Mild false VF medialization	2
	Slight hyperkinesia	3
Disordered (11)	Nodules	4
	Polyps	2
	Chronic laryngitis	1
	Vocal fold atrophy	2
	Reflux disease	1
	Moderate to severe closure insufficiency	1

2.2. Recordings and tasks

Teachers were asked to sustain three times a prolonged vowel [a:] for 5 seconds, followed by reading of a text containing 213 words (no sibilants were included in the text to prevent any speech noise components in the signal considering cepstral sensitivity to noise) at comfortable loudness as in conversational speaking. Additionally, the teachers were asked to read the same text at increased loudness levels as they used during teaching in a large noisy classroom. The voice recordings were carried out in primary schools, in teacher's own classrooms with minimal ambient noise (approximately about 35 dB(A)). Recordings were made using a portable digital recorder (Sony TCD-D8, Sony Corporation, Tokyo, Japan) and an omnidirectional head-mounted microphone (AKGC477, AKG, Vienna, Austria), selected according to the recommendations by Švec and Granqvist (2010)[38] which was maintained at a constant distance of 6 cm, at an angle of 45^{o} from the side of the subject's mouth. The voice recordings were then calibrated using a sound level meter (type 2206 Bruel & Kjaer, Copenhagen) to obtain the true sound pressure level (SPL) of vowel and speech samples.

2.3. SPL calibration procedure and measurement

Calibration was made by using a standard complex sound source (BOSS-TU 120), and a sound level meter (SLM, type 2206, Brüel & Kjaer, Denmark), placed at the same distance and angle from the sound source as the microphone was from the subject's lips. For SLM the slow time averaging and C frequency weighting was used. After the recording, the sound calibration signal was then loaded in *Praat* software. For calibrating the sound levels in the *Praat*, the procedure mentioned by Boersma and Weenink (2013)[39, 40] in the *Praat* manual was used, where the recorded signal was mathematically amplified to obtain the true sound pressure levels (that corresponded to the waveform values in pascals) using the multiplication factor $10^{\left(\frac{\Delta L}{20}\right)}$ where ΔL was the difference level (difference between the true sound pressure level read in the SLM and the uncalibrated level depicted in the *Praat* software). In *Praat* this was done by selecting the signal and choosing the option 'Multiply' from the 'Modify' menu and supplying the multiplication factor.

After the calibration, the steps involved in obtaining the SPL value in *Praat* were as follows:
Voice sample of interest (vowel or speech) was selected in the 'View and edit' window of *Praat.* From the 'Intensity settings' the intensity contour was obtained by selecting the option 'Show intensity'. The following intensity settings were used: view range 40-120 dB, "mean energy" averaging method, and 'subtract mean pressure' chosen (as in standard settings). The final representative SPL value was obtained using the 'Get intensity' option. The final single SPL value obtained this way represents a close approximation of the time-averaged (equivalent) C-weighted sound level for the entire voice sample selected as measured by the sound level meter.[40] Briefly, the time-averaged sound level of a voice signal is equivalent to SPL of a steady sound of the same duration and energy as the selected voice signal, and C-weighting is used by sound level meters when approximating the human hearing for loud sounds. [40]

2.4. Cepstral analysis

Sustained vowel [a:] at comfortable loudness for 3 seconds and 2 first sentences of continuous speech samples (23 syllables) at comfortable and increased loudness were analyzed for all teachers for CPP and CPPS data using software *Praat*. The vowel samples were chosen from the middle and most stable part of the second vowel from the row of three trials recorded. These selections were identical to those used for SPL analysis. The CPP values were obtained using standard *Praat* (version 5.4.05) settings while the CPPS values were extracted with settings recommended by Maryn and Weenink (2015).[3] **Table 2** shows the parameter setting from *Praat* software for the extraction of CPP and CPPS.

Table 2: The steps and parameter setting in the *Praat* software for extraction of CPP and CPPS values for the vowel and continuous speech samples

Step 1) Select the vowel or speech sample Step 2) Go to 'Analyse periodicity' and click on to 'To Power cepstrogram' in the *Praat* Objects window. Step 3) Use the following settings for generating the power cepstrogram:		
Parameter setting	**CPP (standard settings for *Praat* version 5.4.05)**	**CPPS[3]**
Pitch floor (Hz)	60	60
Time step (s)	0.002	0.002
Maximum frequency (Hz)	5000	5000
Pre-emphasis from (Hz)	50	50
Step 4) On selecting the newly generated 'powercepstrogram' click on to 'Query'and select 'Get CPPS' from the menu, and use the following settings:		
Parameter setting	**CPP (standard settings for *Praat* version 5.4.05)**	**CPPS[3]**
Select subtract tilt before smoothing	Yes	No
Time averaging window (s)	0.001	0.01
Quefrency averaging window (s)	0.00005	0.001
Peak search pitch range (Hz)	60-330	60-330
Peak search tolerance (0-1)	0.05	0.05
Interpolation	Parabolic	Parabolic
Tilt line quefrency range (s)	0.001-0.0 (=end)	0.001-0.0 (=end)
Line type	Exponential decay	Straight
Fit method	Robust	Robust

2.5. Perceptual analysis

The same samples of comfortable vowel phonation and comfortable and loud speech reading that were analyzed for cepstral measures were also perceptually analyzed by five experienced voice experts. They used headphones (Sony Stereo headphones MDR-CD480) in the evaluation task. They rated overall voice quality along a ten point unipolar scale from 0 = poor to excellent = 10. Additionally, they evaluated the vocal firmness along a bipolar axis from 0 = breathy through 5 = adequate to 10 = pressed. The listeners could listen to each sample as many times as they liked in order to be sure of the evaluation. The individual listeners' ratings were averaged for each sample to be used in the other statistical analyses.

2.6. Statistical analyses

Kolmogorov-Smirnov test was used to check normal distribution of voice SPL, cepstral measures (CPP and CPPS) and perceptual ratings (voice quality and firmness) for all the three voice samples. To check the inter-rater reliability for the perceptual ratings, Cronbach's alpha test was used. Paired t-test was used to compare voice SPL, CPP, CPPS, voice quality rating and firmness ratings between comfortable vowel and comfortable speech and between comfortable speech and loud speech. Pearson's product moment correlation test was used to find correlation between voice SPL and cepstral measure. Spearman's rank order correlation test was used to find correlations between perceptual ratings, cepstral measures and voice SPL across the three laryngeal status categories (healthy, mild changes and disordered). One way ANOVA was used to compare the voice quality rating, firmness rating, cepstral measures and voice SPLs across the three laryngeal status categories. All the statistical analyses were carried out using SPSS 22 software (IBM SPSS Statistics v. 22 for Windows, Armonk, NY). Significance level was set at $p < 0.05$ in the statistical analyses. MATLAB R2016a was used for scatterplots.

2.7. Ethical approval

Permission for data collection was obtained from school administration and social services departments in the districts in question. Participants volunteered in the study and signed a written consent, which informed them about the aim and procedure in the studies, and stated that the participants may withdraw from the study at any point without any consequences. Handling and preservation of the research material follows the Personal Data Act (523/1999) of Finland.

3. RESULTS

All the measures, CPP, CPPS, SPL, voice quality rating, and rating of firmness for all three voice samples, were normally distributed based on Kolmogorov-Smirnov Test.

3.1. Reliability of perceptual evaluation

The inter-rater reliability of the perceptual evaluation (Table 3) was regarded as adequate based on results of Cronbach's alpha except for rating of voice quality for loud speech which was lower (0.6), and was found questionable, as normally the cutoff value of 0.70 is considered acceptable for reliability.[41]

Table 3: Inter-rater reliability for voice quality and firmness rating for three voice samples

Voice samples	Inter-rater reliability- Cronbach's alpha (α) value	
	Vocal quality	Vocal firmness
Sustained comfortable vowel	0.83	0.80
Comfortable speech	0.82	0.83
Loud speech	0.6 (low and questionable)	0.82

3.2. Acoustic and perceptual results for the three voice tasks:

The results of the acoustic and perceptual evaluations for the three voice tasks are shown in **Table 4**. Furthermore, the results of the paired t-tests evaluating the significance of the differences between the different tasks are shown in Table 5. Together, these tables reveal that: a) The CPP, CPPS and SPL values were significantly larger for sustained vowels than for speech at comfortable loudness; b) The CPP, CPPS and SPL values were significantly larger for loud speech than for comfortable speech; c) Perceptually, the voice quality was found (marginally) significantly better for comfortable vowel than comfortable speech whereas vocal firmness did not show any significant differences here; d) The voices were found to have significantly better quality and more firmness/less breathiness for loud speech than for comfortable speech.

Table 4: The evaluation results expressed through the mean and standard deviation values for the three voice samples

Voice samples	CPP (dB)	CPPS(dB)	Voice SPL(dB)	Voice quality	Vocal Firmness
Sustained vowel	23.4±2.9	13.6±2.1	82.4±5.5	4.7±0.9	5.1±1.0
Comfortable speech	19.0±1.4	10.4±1.5	76.4±3.3	4.4±1.0	4.8±1.2
Loud speech	19.6±1.2	11.4±1.4	84.9±3.8	4.9±1.0	5.7±1.2

Table 5: P values for paired t-test comparing the evaluation results for vowel versus speech at comfortable loudness and for comfortable versus loud speech. Significant values ($p<0.05$) are indicated by *.

Voice samples	CPP	CPPS	SPL	Voice quality	Vocal Firmness
Vowel versus comfortable speech	P<0.001*	P<0.001*	P<0.001*	P=0.040*	P=0.085 (not significant)
Comfortable speech versus loud speech	P<0.001*	P<0.001*	P<0.001*	P<0.001*	P<0.001*

3.3. SPL versus CPP and CPPS for vowel and speech

The next aim was to find the relationship between cepstral and voice SPL measures. **Table 6** shows the Pearson's product moment correlation between the cepstral and voice SPL measures. The results show a positive moderate correlation between voice SPL and both CPP and CPPS for vowel. Also a positive moderate correlation was obtained between voice SPL and CPPS for loud speech and a mild correlation with CPP for loud speech. No significant correlations were obtained between voice SPL and cepstral measures for comfortable speech. However, when the comfortable and loud speech data were pooled together the voice SPL again correlated moderately with both CPP and CPPS measures.

Table 6: Pearson's product moment correlation values and P values for correlations between cepstral measures and voice SPL measures.

Significant values ($p<0.05$) are indicated by *.

Voice SPL	CPP		CPPS	
	Correlation value (r)	Sig. (2-tailed)	Correlation value (r)	Sig. (2-tailed)
Vowel	0.45	P<0.001*	0.49	P<0.001*
Comfortable speech	0.16	P=0.137	0.18	P=0.096
Loud speech	0.28	P=0.009*	0.45	P<0.001*
Combined comfortable and loud speech	0.31	P<0.001*	0.43	P<0.001*

The relationship between the SPL and the cepstral measures is demonstrated more clearly in **Figure 1**. For sustained vowel the regression line through the data revealed these relationships:

$CPP = 0.24 * SPL + 3.7$ and $CPPS = 0.18 * SPL - 1.4$ (eq. 1a,b)

These relationships indicate that for a 10 dB increase in SPL there was, on average, 2.4 dB increase in CPP and 1.8 dB increases in CPPS. Also, when exploring these relationships we may find e.g. that for the SPL of 80 dB the CPP and CPPS reached the average values of 22.9 dB and 13 dB, respectively.

For speech, both comfortable and loud pooled together, linear regression revealed these relationships:

$CPP = 0.073 * SPL + 13$ and $CPPS = 0.12 * SPL + 1.5$ (eq. 2a,b)

These relationships indicate that for a 10 dB increase in SPL there was, on average, 0.7 dB increase in CPP and 1.2 dB increase in CPPS. For the SPL of 80 dB the corresponding average CPP and CPPS values were 18.8 dB and 11.1 dB, respectively.

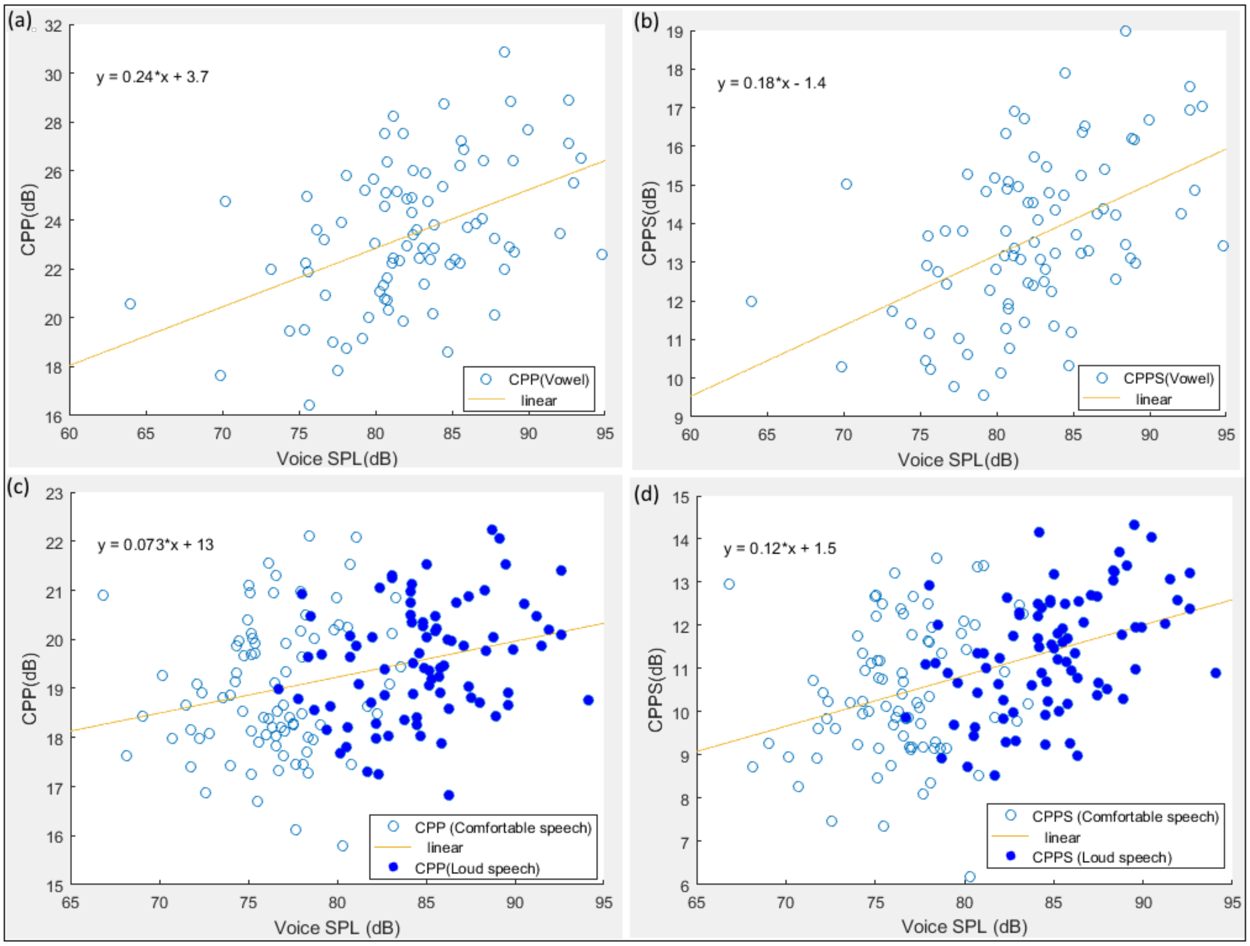

Figure 1: A scatterplot showing relationship between time-averaged equivalent SPL (at 6 cm distance in dB re 20 μPa) and the two cepstral measures for sustained vowel [a, b] and speech [c, d]. The speech data contain both the comfortable (empty circles) and loud (filled circles) conditions together. Notice the linear regression lines with their equation shown in each of the graphs – all of them show the trend of CPP/CPPS increase with increased SPL.

3.4. Voice perception versus laryngeal pathology

None of the perceptual ratings correlated with the laryngeal status findings for any of the vocal tasks according to the Spearman's rank order correlation. Also results of one way ANOVA test showed no significant differences across the three laryngeal status categories (P>0.05) for the perceptual ratings of voice quality and firmness. Also, no systematic trends were found across the different laryngeal status categories. The numerical results are shown in **Table 7.**

Table7: Mean, standard deviation (SD) and standard error (SE) of perceptual rating for all three voice samples for teachers grouped under the laryngeal status category

Laryngeal status category	N	Voice quality rating			Firmness rating		
		Vowel	Comfortable speech	Loud speech	Vowel	Comfortable speech	Loud speech
		Mean±SD (SE)	Mean ±SD (SE)	Mean±SD (SE)	Mean±SD (SE)	Mean±SD (SE)	Mean±SD (SE)
Healthy	40	4.7±0.9 (0.14)	4.1±1 (0.15)	4.9±0.9 (0.14)	5.1±0.9 (0.14)	4.6±1.3 (0.20)	5.7±1.3 (0.21)
Mild	33	4.8±0.9 (0.15)	4.7±1.1 (0.18)	5±1 (0.17)	5.2±1 (0.17)	4.9±1.1 (0.18)	5.8±1.1 (0.19)
Disordered	11	4.4±0.6 (0.18)	4.5±0.9 (0.26)	4.9±1 (0.30)	4.6±0.6 (0.18)	4.9±1.4 (0.43)	5.6±1.1 (0.32)

3.5. Cepstral measures versus laryngeal pathology

Similar to the perceptual ratings, none of the acoustic measures (CPP, CPPS or SPL) correlated with laryngeal status categories, for any of the three voice samples according to the Spearman's rank order correlation test. Also results of ANOVA showed no significant differences for the acoustic measures across the three groups divided on the basis of laryngeal status evaluation ($P>0.05$). Nevertheless, the data showed systematic decrease of the CPP, CPPS and SPL values from healthy to mild to disordered category in all the three voice samples. The numerical results are shown in **Table 8**.

Table 8: Mean, standard deviation (SD) and standard error (SE) of cepstral values (in dB) and of the time-averaged equivalent SPL at 6 cm distance (in dB re 20 μPa) for all three voice samples for teachers grouped under the laryngeal status category

laryngeal status category	N	Vowel			Comfortable speech			Loud speech		
		CPP	CPPS	SPL	CPP	CPPS	SPL	CPP	CPPS	SPL
		Mean ±SD (SE)	Mean ±SD (SE)	Mean ±SD (SE)	Mean ±SD (SE)	Mean ±SD (SE)	Mean ±SD (SE)	Mean ±SD (SE)	Mean ±SD (SE)	Mean ±SD (SE)
Healthy	40	23.8 ±2.6 (0.41)	13.9± 1.9 (0.30)	83.2 ±6.1 (0.97)	19.0 ±1.5 (0.23)	10.5 ±1.2 (0.25)	77.0 ±3.0 (0.47)	19.7 ±1.3 (0.20)	11.5 ±1.5 (0.23)	85.0 ±3.8 (0.60)
Mild	33	23.0 ±3.4 (0.59)	13.4 ±2.4 (0.41)	81.8 ±5.2 (0.90)	19 ±1.2 (0.21)	10.4 ±1.5 (0.26)	76.2 ±3.9 (0.68)	19.5 ±1.1 (0.18)	11.3 ±1.2 (0.21)	85.0 ±4.1 (0.70)
Disordered	11	23.0 ±2.3 (0.68)	13.3 ±1.6 (0.49)	81± 3.5 (1.06)	18.8 ±1.4 (0.43)	10.1 ±1.5 (0.44)	74.9 ±2.1 (0.62)	19.4 ±1.4 (0.32)	11.2 ±1.2 (0.38)	84.0 ±2.9 (0.88)

4. DISCUSSION

Sustained vowels and speech at comfortable loudness are standard tasks used in clinical evaluation of voice.[4, 42-44] As teachers often use loud speech when teaching, in this study we also added speaking at raised loudness levels as a third voice task. We were interested in finding out how these tasks influence the CPP, CPPS and SPL values and perceptual ratings of vocal quality and firmness in teachers who considered themselves to have normal voice. Furthermore, since in some of the teachers laryngeal pathologies were detected laryngoscopically, we were interested in finding out whether some of these evaluations can help detecting these underlying vocal pathologies despite of them not being self-perceived by the teachers.

CPP and CPPS measures started to be explored after Hillenbrand[1, 2, 45] developed the *SpeechTool* software (James Hillenbrand; Western Michigan University, Kalamazoo, MI, USA—https://homepages.wmich.edu/~hillenbr/), for the extraction of the cepstral peak prominence measures from the voice samples. After then, the cepstral measures have been implemented also in other software packages such as *Computerized Speech Lab* (CSL, Kay Pentax, Lincoln Park, NJ) and the freely available *Praat*[3] (Paul Boersma and David Weenink, Institute of Phonetic Sciences - University of Amsterdam, The Netherlands-http://www.praat.org/). Since their implementation in 2015, the cepstral measures in *Praat* have been used in measuring the cepstral values in normophonic and dysphonic individuals.[3, 17, 46] The authors Maryn and Weenink[3] reported that the CPPS values (for both vowel and continuous speech sample) obtained from *Praat* were a 'highly acceptable approximation' of CPPS obtained from *SpeechTool* software.[1, 2] Also Sauder et al.[17] reported that the smoothed CPP for connected speech samples derived from *Praat* software, had a high rate of accuracy in predicting voice disorder status with excellent sensitivity value of 90% on the area under the receiver operating characteristic curve (ROC). Nevertheless, CPP and CPPS results obtained from the same voice samples using different software packages yield different absolute values.[46-48] In this paper we aimed at measuring the CPP and CPPS values extracted from *Praat* software and relating them to SPL and perceptual evaluations of voice quality and vocal firmness.

From Table 4 and 5 we can observe that the CPP, CPPS values were significantly larger (on average by 4.4 dB and 3.2 dB, respectively) for comfortable sustained vowels compared to comfortable speech. This is an expected result, because speech contains fundamental frequency and intensity fluctuations, voice onsets and offsets, vocal pauses, etc., all of which decrease the prominence of harmonic organization over the noise content measured by the CPP and CPPS parameters.[49 50] The comfortable vowel SPL was also, on average, 6 dB larger than comfortable speech SPL – this can be attributed particularly to the fact that the speech samples included, besides vowels and consonants, also pauses between the syllables, words and sentences, which decrease the average sound level of the total speech sample compared to sustained vowels.

As far as the loud versus comfortable speech comparisons are concerned, Table 4 reveals that the SPL increased on average by 6 dB from comfortable to loud speech and the CPP and CPPS values were significantly higher (on average by 0.6 and 1 dB, respectively) for loud than for comfortable speech in our teachers. This significant trend of increasing CPP and CPPS values with increased SPL is more explicitly shown through the regression lines in Figure 1 which are quantified and mathematically expressed through equations 1 and 2. The cepstral prominence dependencies on SPL are slightly different for vowels than for speech, but the trend is the same in both vocal tasks. This relationship confirms the previous findings that the cepstral measures increase with increasing SPL of voice.[36] No significance was found in our results for data from comfortable speech only (Table 6), which we attribute to a smaller range of SPLs observed in this vocal task in combination with the rather large spread of CPP and CPPS values for the different individuals (recall Figure 1c and d, data indicated by empty circles only). The trend became highly significant ($p<0.001$) when the SPL range was enlarged by pooling the comfortable and loud conditions together (both empty and filled circles in Figures 1c and d).Thee relationship between voice SPL and cepstral peak prominence values may be related to previous findings that increased phonational loudness decreases the perturbation in voice[51] thus leading to increase in CPP/CPPS values of vowel phonation.[36] This has been related to an increase in the medial compression of vocal folds that improves the glottal closure,[36, 52] (this assumption is supported here by our perceptual findings of increased firmness in loud voice, as indicated in Table 4) and there is also greater vocal tract excitation resulting in a signal with strong overtones.[36] It is interesting to compare our CPP and CPPS results to those found in other studies for healthy and disordered subjects. Here, the CPP and CPPS settings also need to be considered. Our CPPS measurement procedure and settings were identical to those specified for measuring the Acoustic Voice Quality Index (AVQI) using *Praat* software.[3] The mean CPPS values for all the teachers in this study (vowel: 13.6±2.1 dB; comfortable speech: 10.4±1.5 dB; and loud speech: 11.4±1.4 dB) are similar to the results of CPPS obtained by Maryn and Weenink (2015)[3] using *Praat* software on a group of 289 normal and dysphonic individuals). They report a CPPS value of 11.66±2.68 dB for a concatenated voice sample which combines 3 s vowel sample and connected speech together in one file.[3, 53] Also our CPPS results are in good correspondence with those obtained by Latoszek et al (2017)[54] using the AVQI based CPPS setup (*Praat* version 5.3.57), where they report a mean CPPS value of 11.92±2.15 dB in individuals with perceptually non-rough voices. Our CPP values (23.4±2.9dB for vowel and 19.0±1.4dB for comfortable speech) are also in correspondence to the CPP values obtained by Watts et al (2017)[46] who also used *Praat* software for extracting CPP values. The authors reported a CPP value of 22.86±4.07dB for English vowel and 20.07±3.33dB for English sentence on a group of 22 dysphonic and 22 non-dysphonic speakers.

On the other hand, our results for CPPS are different from those obtained by Sauder et al. (2017),[17] where they report a value of 20.11±1.27dB for nondysphonic subjects on continuous speech sample using the default *Praat* (version 6.0.17) settings. These values, however, are close to our CPP speech values (19.0±1.4 dB for comfortable and 19.6±1.2 dB for loud speech). We therefore suspect that the CPPS values reported by Sauder et al. (2017),[17] may not be the smoothed CPPS values but rather the non-smoothed CPP ones as we have discovered that the current default *Praat* CPPS settings use the time averaging window of 0.001 s and quefrency averaging window of

0.00005 s which are so short that effectively no smoothing takes place. Different *Praat* versions provide different default settings, and therefore one needs to be cautious in selecting the parameter settings for smoothing.

Different settings and methodology may also explain differences of CPPS values among different software packages. Similarly to the findings of Maryn and Weenink[3] our *Praat*-based CPPS results do not match the values obtained from Hillenbrand's *SpeechTool* software in various other studies[19, 20, 22, 55, 56] due to differences in the algorithms used in these softwares. For example Balasubramanium et al.[56] reported a mean CPP value of 13.65±0.9dB and mean CPPS value of 6.30±0.35dB for vowel sample on 22 normal subjects using *SpeechTool* software and Heman-Ackah et al.[55] reported a mean CPPS value of 4.77±0.97dB in 30 normal voices on a running speech sample. Therefore, choosing appropriate software and accurate parameter settings is an important consideration when performing cepstral analysis of voice. There is a need to unify and standardize the CPP and CPPS measurement procedures in future so that the data are reproducible and better comparable. Since CPP and CPPS measures have been reported to correlate with perceptual ratings of voice quality[2, 6, 8], perceptual evaluations were also included in this study. The inter-rater reliability of the vocal quality and firmness (Table 3) was adequate for all the voice samples except for the loud speech sample which had low and questionable α value. This may be due to different internal standards of the raters for loud speech perception. The evaluation of loud speech is more complex than of comfortable speech or vowel, because the raters (who were speech language pathologists) may have been prejudiced by their different expectancy on how the loud speech should be produced in loud voice and what could be potentially unhealthy.
Tables 4 and 5 reveal that the voice quality was slightly better for comfortable vowel than comfortable speech. This may be due to the fact that speech samples are more demanding on laryngeal coordination and expose voice abnormalities more extensively than sustained vowels.[57] However, the voice quality values approached value of 5 (on the rating scale of 0 = poor to excellent = 10) for both vowel and comfortable speech samples indicating, on average, good voice quality in these teachers. The vocal firmness did not show any significant differences between sustained vowels and comfortable speech and their values as well approached normal values along the continuum from breathy (0) through normal (5) to pressed (10), suggesting normal vocal fold adduction in these teachers.

The perceptual differences were much more prominent between the comfortable and loud speech samples than between comfortable vowels and comfortable speech. The voices were found to have significantly better quality and more firmness/less breathiness for loud speech. This can be related to the reduction of voice perturbations increased vocal loudness.[36] The mean values for firmness ratings in loud speech samples (5.7±1.2, Table 4) suggest that the voices were neither breathy nor pressed, suggesting that the teachers on average did not have the tendency to endanger their larynges by inadequate voice production mechanisms. This may be related to the fact that the teachers had no vocal complaints.

Nevertheless, since in some of the teachers laryngeal pathologies were detected laryngoscopically, another goal of the present study was to find out whether the expert perceptual evaluations, cepstral measures and voice SPL measures could reveal some vocal changes due to the underlying pathology (section 3.4, 3.5 and 3.6 of results). The results of one way ANOVA test did not show any systematic differences for perceptual ratings across the laryngeal status categories (healthy, mild changes, disordered), and no significant correlations were found between the perceptual and laryngeal status evaluation. From Table 7 it can be seen that the voice quality and firmness ratings do not show any specific trends. This indicates that the laryngeal pathologies were not well perceivable by the voice expert listeners.

Similar to perceptual evaluations, also the acoustic measures did not show statistically significant differences among or correlations with the laryngeal status categories for any of the vocal tasks. Nevertheless, a closer look at the results in Table 8 revealed that, in contrast to the perceptual evaluations, the cepstral measures (both CPP and CPPS) and SPL values (for all three voice samples), show a consistent decline in the mean values with increased severity of the laryngeal pathology. This suggests that the cepstral and SPL measures could be more sensitive to the underlying vocal pathology than the perceptual measures. However, the differences among the disordered vs. nondisordered groups were only around 0.2 dB for CPP and CPPS and 2 dB for SPL (Table 8) which are much smaller compared to the standard deviations which were above 1 dB (for CPP and CPPS) and above 2.9 dB (for SPL) within each category. This indicates that the CPP, CPPS and SPL variability among healthy larynges was larger than the influence of the underlying laryngeal pathology in our teachers.

Considering this and the fact that all the teachers considered themselves to have a normal voice, they may be as such referred to having a *functionally healthy voice.* The large variability with respect to the small effect of the laryngeal pathology limits the possibility of using solely the CPP, CPPS and SPL measures for detecting the laryngeal pathology in individual teachers. Nevertheless, the trend of CPP, CPPS and SPL lowering with underlying laryngeal pathology can be explored in future for detecting differences among the groups of pathologic and control subjects. In this study, the pathologic group size was limited to only 11 teachers causing the standard error of the mean to be rather large for finding significant differences. Future studies may explore the differences with a larger number of subjects in which the standard error of the mean is expected to be smaller thus revealing better on potential significant differences among different subject groups.

5. CONCLUSION

The present study brings basic information on CPP and CPPS values in teachers without vocal complaints and their relationships to voice SPL, voice quality, firmness of voice, and underlying laryngeal pathologies. The results show that with increased loudness and SPL, the cepstral values increased and the voice became firmer without becoming excessively pressed. Although the teachers considered themselves vocally healthy, 52.4% of them had some laryngeal changes detected laryngoscopically. These underlying pathologies, however, did not significantly correlate with none of the acoustic measures not with the perceptual judgments of voice quality and firmness confirming the self-perception of the teachers that their voices were functionally healthy. Nevertheless, the cepstral measures and voice SPLs showed a consistent decline in their values with increased severity of laryngeal pathology. This trend may further be explored in future studies.

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REFERENCES

1. Hillenbrand J, Cleveland RA, Erickson RL. Acoustic correlates of breathy vocal quality. *Journal of Speech, Language, and Hearing Research.* 1994;37:769-778.

2. Hillenbrand J, Houde RA. Acoustic correlates of breathy vocal quality: dysphonic voices and continuous speech. *Journal of Speech, Language, and Hearing Research.* 1996;39:311-321.

3. Maryn Y, Weenink D. Objective dysphonia measures in the program Praat: smoothed cepstral peak prominence and acoustic voice quality index. *Journal of Voice.* 2015;29:35-43.

4. Patel R, Awan SN, Barkmeier-Kraemer J, et al. Recommended Protocols for Instrumental Assessment of Voice: American Speech-Language-Hearing Association Expert Panel to Develop a Protocol for Instrumental Assessment of Vocal Function. *American journal of speech-language pathology.* 2018:1-19.

5. Heman-Ackah YD, Michael DD, Baroody MM, et al. Cepstral peak prominence: a more reliable measure of dysphonia. *Annals of Otology, Rhinology & Laryngology.* 2003;112:324-333.

6. Heman-Ackah YD, Michael DD, Goding GS. The Relationship Between Cepstral Peak Prominence and Selected Parameters of Dysphonia. *Journal of Voice.* 2002;16:20-27.

7. Leong K, Hawkshaw MJ, Dentchev D, Gupta R, Lurie D, Sataloff RT. Reliability of objective voice measures of normal speaking voices. *Journal of voice : official journal of the Voice Foundation.* 2013;27:170-176.

8. Awan SN, Roy N, Jette ME, Meltzner GS, Hillman RE. Quantifying dysphonia severity using a spectral/cepstral-based acoustic index: Comparisons with auditory-perceptual judgements from the CAPE-V. *Clinical linguistics & phonetics.* 2010;24:742-758.

9. Shue Y-L, Chen G, Alwan A. On the interdependencies between voice quality, glottal gaps, and voice-source related acoustic measures. *Eleventh Annual Conference of the International Speech Communication Association.INTERSPEECH 2010:34-37.* 2010.

10. Wolfe V, Martin D. Acoustic correlates of dysphonia: type and severity. *Journal of Communication Disorders.* 1997;30:403-416.

11. Awan SN, Roy N. Acoustic prediction of voice type in women with functional dysphonia. *Journal of Voice.* 2005;19:268-282.

12. Watts CR, Awan SN. Use of spectral/cepstral analyses for differentiating normal from hypofunctional voices in sustained vowel and continuous speech contexts. *Journal of Speech, Language, and Hearing Research.* 2011;54:1525-1537.

13. Lowell SY, Kelley RT, Awan SN, Colton RH, Chan NH. Spectral-and cepstral-based acoustic features of dysphonic, strained voice quality. *Annals of Otology, Rhinology & Laryngology.* 2012;121:539-548.

14. Zieger K, Schneider C, Gerull G, Mrowinski D. Cepstrum analysis in voice disorders. *Folia phoniatrica et logopaedica: official organ of the International Association of Logopedics and Phoniatrics (IALP).* 1995;47:210-217.

15. Radish Kumar B, Bhat JS, Prasad N. Cepstral analysis of voice in persons with vocal nodules. *Journal of voice : official journal of the Voice Foundation.* 2010;24:651-653.

16. Balasubramanium RK, Bhat JS, Fahim S, 3rd, Raju R, 3rd. Cepstral analysis of voice in unilateral adductor vocal fold palsy. *Journal of voice : official journal of the Voice Foundation.* 2011;25:326-329.

17. Sauder C, Bretl M, Eadie T. Predicting voice disorder status from smoothed measures of cepstral peak prominence using Praat and analysis of dysphonia in speech and voice (ADSV). *Journal of Voice.* 2017;31:557-566.

18. Hasanvand A, Salehi A, Ebrahimipour M. A cepstral analysis of normal and pathologic voice qualities in Iranian adults: a comparative study. *Journal of Voice.* 2017;31:508. e517-508. e523.

19. Brinca LF, Batista AP, Tavares AI, Goncalves IC, Moreno ML. Use of cepstral analyses for differentiating normal from dysphonic voices: a comparative study of connected speech versus sustained vowel in European Portuguese female speakers. *Journal of voice : official journal of the Voice Foundation.* 2014;28:282-286.

20. Moers C, Möbius B, Rosanowski F, Nöth E, Eysholdt U, Haderlein T. Vowel-and text-based cepstral analysis of chronic hoarseness. *Journal of Voice.* 2012;26:416-424.

21. Warhurst S, McCabe P, Yiu E, Heard R, Madill C. Acoustic characteristics of male commercial and public radio broadcast voices. *Journal of Voice.* 2013;27:655. e651-655. e657.

22. Balasubramanium RK, Shastry A, Singh M, Bhat JS. Cepstral characteristics of voice in Indian female classical carnatic singers. *Journal of Voice.* 2015;29:693-695.

23. Vilkman E. Voice problems at work: a challenge for occupational safety and health arrangement. *Folia phoniatrica et logopaedica.* 2000;52:120-125.

24. Rantala LM, Hakala S, Holmqvist S, Sala E. Classroom noise and teachers' voice production. *Journal of Speech, Language, and Hearing Research.* 2015;58:1397-1406.

25. Cutiva LCC, Puglisi GE, Astolfi A, Carullo A. Four-day follow-up study on the self-reported voice condition and noise condition of teachers: Relationship between vocal parameters and classroom acoustics. *Journal of Voice.* 2017;31:120.e121-120.e128.

26. Durup N, Shield BM, Dance S, Sullivan R. Teachers' voice parameters and classroom acoustics—A field study and online survey. *The Journal of the Acoustical Society of America.* 2017;141:3540-3540.

27. Kankare E, Geneid A, Laukkanen A-M, Vilkman E. Subjective evaluation of voice and working conditions and phoniatric examination in kindergarten teachers. *Folia Phoniatrica et Logopaedica.* 2012;64:12-19.

28. Cutiva LCC, Vogel I, Burdorf A. Voice disorders in teachers and their associations with work-related factors: a systematic review. *Journal of Communication Disorders.* 2013;46:143-155.

29. Bolbol SA, Zalat MM, Hammam RA, Elnakeb NL. Risk Factors of Voice Disorders and Impact of Vocal Hygiene Awareness Program Among Teachers in Public Schools in Egypt. *Journal of Voice.* 2017;31:251. e259-251. e216.

30. Ilomäki I, Mäki E, Laukkanen A-M. Vocal symptoms among teachers with and without voice education. *Logopedics Phoniatrics Vocology.* 2005;30:171-174.

31. Simberg S, Sala E, Vehmas K, Laine A. Changes in the prevalence of vocal symptoms among teachers during a twelve-year period. *Journal of Voice.* 2005;19:95-102.

32. 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;15:413-423.

33. Södersten M, Granqvist S, Hammarberg B, Szabo A. Vocal behavior and vocal loading factors for preschool teachers at work studied with binaural DAT recordings. *Journal of Voice.* 2002;16:356-371.

34. Phadke KV, Abo-Hasseba A, Švec JG, Geneid A. Influence of Noise Resulting From the Location and Conditions of Classrooms and Schools in Upper Egypt on Teachers' Voices. *Journal of Voice.* 2018.

35. Abo-Hasseba A, Waaramaa T, Alku P, Geneid A. Difference in voice problems and noise reports between teachers of public and private schools in Upper Egypt. *Journal of Voice.* 2017;31:508. e511-508. e516.

36. Awan SN, Giovinco A, Owens J. Effects of vocal intensity and vowel type on cepstral analysis of voice. *Journal of voice.* 2012;26:670. e615-670. e620.

37. Ilomäki I, Leppänen K, Kleemola L, Tyrmi J, Laukkanen A-M, Vilkman E. Relationships between self-evaluations of voice and working conditions, background factors, and phoniatric findings in female teachers. *Logopedics Phoniatrics Vocology.* 2009;34:20-31.

38. Svec JG, Granqvist S. Guidelines for selecting microphones for human voice production research. *American Journal of Speech-Language Pathology.* 2010;19:356-368.

39. Boersma P, Weenink D. Praat: Doing phonetics by computer. Amsterdam, the Netherlands: Institute of Phonetic Sciences, University of Amsterdam. 2013 http://www.fon.hum.uva.nl/praat/manual/sound_pressure_calibration.html.

40. Švec JG, Granqvist S. Tutorial and Guidelines on Measurement of Sound Pressure Level in Voice and Speech. *Journal of Speech, Language, and Hearing Research.* 2018;61:441-461.

41. Santos JRA. Cronbach's alpha: A tool for assessing the reliability of scales. *Journal of extension.* 1999;37:1-5.

42. Oates J. Auditory-perceptual evaluation of disordered voice quality. *Folia Phoniatrica et Logopaedica.* 2009;61:49-56.

43. Barsties B, De Bodt M. Assessment of voice quality: current state-of-the-art. *Auris, nasus, larynx.* 2015;42:183-188.

44. Dejonckere PH, Bradley P, Clemente P, et al. A basic protocol for functional assessment of voice pathology, especially for investigating the efficacy of (phonosurgical) treatments and evaluating new assessment techniques. *European Archives of Oto-rhino-laryngology.* 2001;258:77-82.

45. Hillenbrand JS. Version 1.56 [computer program], 2006.

46. Watts CR, Awan SN, Maryn Y. A comparison of cepstral peak prominence measures from two acoustic analysis programs. *Journal of Voice.* 2017;31:387. e381-387. e310.

47. Kim G, Lee Y, Park H, Bae I, Kwon S. A study of cepstral peak prominence characteristics in ADSV, SpeechTool and Praat. *Journal of Speech-Language & Hearing Disorders.* 2017;26:99-111.

48. Madill C, Nguyen DD, Eastwood C, Heard R, Warhurst S. Comparison of Cepstral Peak Prominence Measures Using the ADSV, SpeechTool, and VoiceSauce Acoustic Analysis Programs in Vocally Healthy Female Speakers. *Acoustics Australia.* 2018:1-12.

49. Zhang Y, Jiang JJ. Acoustic analyses of sustained and running voices from patients with laryngeal pathologies. *Journal of Voice.* 2008;22:1-9.

50. Maryn Y, Roy N. Sustained vowels and continuous speech in the auditory-perceptual evaluation of dysphonia severity. *Jornal da Sociedade Brasileira de Fonoaudiologia.* 2012;24:107-112.

51. Brockmann M, Storck C, Carding PN, Drinnan MJ. Voice loudness and gender effects on jitter and shimmer in healthy adults. *Journal of Speech, Language, and Hearing Research.* 2008;51:1152-1160.

52. Sulter A, Albers F. The effects of frequency and intensity level on glottal closure in normal subjects. *Clinical Otolaryngology & Allied Sciences.* 1996;21:324-327.

53. Maryn Y, Corthals P, Van Cauwenberge P, Roy N, De Bodt M. Toward improved ecological validity in the acoustic measurement of overall voice quality: combining continuous speech and sustained vowels. *Journal of voice.* 2010;24:540-555.

54. Latoszek BBv, De Bodt M, Gerrits E, Maryn Y. The exploration of an objective model for roughness with several acoustic markers. *Journal of Voice.* 2017.

55. Heman-Ackah YD, Sataloff RT, Laureyns G, et al. Quantifying the cepstral peak prominence, a measure of dysphonia. *Journal of voice : official journal of the Voice Foundation.* 2014;28:783-788.

56. Balasubramanium RK, Karuppali S, Bajaj G, Shastry A, Bhat J. Acoustic-Perceptual Correlates of Voice in Indian Hindu Purohits. *Journal of Voice.* 2018.

57. Law T, Kim JH, Lee KY, et al. Comparison of rater's reliability on perceptual evaluation of different types of voice sample. *Journal of Voice.* 2012;26:666. e613-666. e621.

Ignore the following references

1. Hillenbrand J, Cleveland RA, Erickson RL. Acoustic correlates of breathy vocal quality. *Journal of Speech, Language, and Hearing Research.* 1994;37:769-778. doi:10.1044/jshr.3704.769

2. Hillenbrand J, Houde RA. Acoustic correlates of breathy vocal quality: dysphonic voices and continuous speech. *Journal of Speech, Language, and Hearing Research.* 1996;39:311-321. doi:10.1044/jshr.3902.311

3. Maryn Y, Weenink D. Objective dysphonia measures in the program Praat: smoothed cepstral peak prominence and acoustic voice quality index. *Journal of voice.* 2015;29:35-43. doi: https://doi.org/10.1016/j.jvoice.2014.06.015

4. Heman-Ackah YD, Michael DD, Baroody MM, et al. Cepstral peak prominence: a more reliable measure of dysphonia. *Annals of Otology, Rhinology & Laryngology.* 2003;112:324-333.doi: https://doi.org/10.1177/000348940311200406

5. Heman-Ackah YD, Michael DD, Goding GS. The Relationship Between Cepstral Peak Prominence and Selected Parameters of Dysphonia. *Journal of Voice.* 2002;16:20-27. doi: https://doi.org/10.1016/S0892-1997(02)00067-X

6. Leong K, Hawkshaw MJ, Dentchev D, Gupta R, Lurie D, Sataloff RT. Reliability of objective voice measures of normal speaking voices. *Journal of voice.* 2013;27:170-176. doi: https://doi.org/10.1016/j.jvoice.2012.07.005

7. Awan SN, Roy N, Jette ME, Meltzner GS, Hillman RE. Quantifying dysphonia severity using a spectral/cepstral-based acoustic index: Comparisons with auditory-perceptual judgements from the CAPE-V. *Clinical linguistics & phonetics.* 2010;24:742-758. doi: https://doi.org/10.3109/02699206.2010.492446

8. Shue Y-L, Chen G, Alwan A. On the interdependencies between voice quality, glottal gaps, and voice-source related acoustic measures. *Eleventh Annual Conference of the International Speech Communication Association.INTERSPEECH* 2010:34-37. https://www.isca-speech.org/archive/interspeech_2010/i10_0034.html

9. Wolfe V, Martin D. Acoustic correlates of dysphonia: type and severity. *Journal of Communication Disorders.* 1997;30:403-416.doi: https://doi.org/10.1016/S0021-9924(96)00112-8

10. Awan SN, Roy N. Acoustic prediction of voice type in women with functional dysphonia. *Journal of Voice.* 2005;19:268-282.doi: https://doi.org/10.1016/j.jvoice.2004.03.005

11. Watts CR, Awan SN. Use of spectral/cepstral analyses for differentiating normal from hypofunctional voices in sustained vowel and continuous speech contexts. *Journal of Speech, Language, and Hearing Research.* 2011;54:1525-1537. doi:10.1044/1092-4388(2011/10-0209)

12. Lowell SY, Kelley RT, Awan SN, Colton RH, Chan NH. Spectral-and cepstral-based acoustic features of dysphonic, strained voice quality. *Annals of Otology, Rhinology & Laryngology.* 2012;121:539-548.doi: https://doi.org/10.1177/000348941212100808

13. Zieger K, Schneider C, Gerull G, Mrowinski D. Cepstrum analysis in voice disorders. *Folia phoniatrica et logopaedica.*1995;47(4):210-217.doi:10.1159/000266352

14. Radish Kumar B, Bhat JS, Prasad N. Cepstral analysis of voice in persons with vocal nodules. *Journal of voice.* 2010;24:651-653.doi: https://doi.org/10.1016/j.jvoice.2009.07.008

15. Balasubramanium RK, Bhat JS, Fahim S, Raju R. Cepstral analysis of voice in unilateral adductor vocal fold palsy. *Journal of voice.* 2011;25:326-329.doi: https://doi.org/10.1016/j.jvoice.2009.12.010

16. Sauder C, Bretl M, Eadie T. Predicting voice disorder status from smoothed measures of cepstral peak prominence using Praat and analysis of dysphonia in speech and voice (ADSV). *Journal of Voice.* 2017;31:557-566.doi: https://doi.org/10.1016/j.jvoice.2017.01.006

17. Fraile R, Godino-Llorente JI. Cepstral peak prominence: A comprehensive analysis. *Biomedical Signal Processing and Control.* 2014;14:42-54.doi: https://doi.org/10.1016/j.bspc.2014.07.001

18. Hasanvand A, Salehi A, Ebrahimipour M. A cepstral analysis of normal and pathologic voice qualities in Iranian adults: a comparative study. *Journal of Voice.* 2017;31:508.e17-508.e23. doi: https://doi.org/10.1016/j.jvoice.2016.10.017

19. Brinca LF, Batista AP, Tavares AI, Goncalves IC, Moreno ML. Use of cepstral analyses for differentiating normal from dysphonic voices: a comparative study of connected speech versus sustained vowel in European Portuguese female speakers. *Journal of voice.* 2014;28:282-286. doi: https://doi.org/10.1016/j.jvoice.2013.10.001

20. Moers C, Möbius B, Rosanowski F, Nöth E, Eysholdt U, Haderlein T. Vowel-and text-based cepstral analysis of chronic hoarseness. *Journal of Voice.* 2012;26:416-424. doi: https://doi.org/10.1016/j.jvoice.2011.05.001

21. Warhurst S, McCabe P, Yiu E, Heard R, Madill C. Acoustic characteristics of male commercial and public radio broadcast voices. *Journal of Voice.* 2013;27:655. 655.e1-655.e7.doi: https://doi.org/10.1016/j.jvoice.2013.04.012

22. Balasubramanium RK, Shastry A, Singh M, Bhat JS. Cepstral characteristics of voice in Indian female classical carnatic singers. *Journal of Voice.* 2015;29:693-695.doi: https://doi.org/10.1016/j.jvoice.2015.01.002

23. Vilkman E. Voice problems at work: a challenge for occupational safety and health arrangement. *Folia phoniatrica et logopaedica.* 2000;52:120-125.doi: https://doi.org/10.1159/000021519

24. Rantala LM, Hakala S, Holmqvist S, Sala E. Classroom noise and teachers' voice production. *Journal of Speech, Language, and Hearing Research.* 2015;58:1397-1406. doi:10.1044/2015_JSLHR-S-14-0248

25. Cutiva LCC, Puglisi GE, Astolfi A, Carullo A. Four-day follow-up study on the self-reported voice condition and noise condition of teachers: Relationship between vocal parameters and classroom acoustics. *Journal of Voice.* 2017;31:120.e1–120.e8. doi: https://doi.org/10.1016/j.jvoice.2016.02.017

26. Durup N, Shield BM, Dance S, Sullivan R. Teachers' voice parameters and classroom acoustics—A field study and online survey. *The Journal of the Acoustical Society of America.* 2017;141:3540.doi: https://doi.org/10.1121/1.4987482

27. Kankare E, Geneid A, Laukkanen A-M, Vilkman E. Subjective evaluation of voice and working conditions and phoniatric examination in kindergarten teachers. *Folia Phoniatrica et Logopaedica.* 2012;64:12-19.doi: https://doi.org/10.1159/000328643

28. Cutiva LCC, Vogel I, Burdorf A. Voice disorders in teachers and their associations with work-related factors: a systematic review. *Journal of Communication Disorders.* 2013;46:143-155.doi: https://doi.org/10.1016/j.jcomdis.2013.01.001

29. Bolbol SA, Zalat MM, Hammam RA, Elnakeb NL. Risk Factors of Voice Disorders and Impact of Vocal Hygiene Awareness Program Among Teachers in Public Schools in Egypt. *Journal of Voice.* 2017;31: 251.e9–251.e16.doi: https://doi.org/10.1016/j.jvoice.2016.07.010

30. Ilomäki I, Mäki E, Laukkanen A-M. Vocal symptoms among teachers with and without voice education. *Logopedics Phoniatrics Vocology.* 2005;30:171-174.doi: https://doi.org/10.1080/14015430500294106

31. Simberg S, Sala E, Vehmas K, Laine A. Changes in the prevalence of vocal symptoms among teachers during a twelve-year period. *Journal of Voice.* 2005;19:95-102.doi: https://doi.org/10.1016/j.jvoice.2004.02.009

32. 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;15:413-423.doi: https://doi.org/10.1016/S0892-1997(01)00042-X

33. Ilomäki I, Kankare E, Tyrmi J, Kleemola L, Geneid A. Vocal fatigue symptoms and laryngeal status in relation to vocal activity limitation and participation restriction. *Journal of Voice.* 2017;31: 248.e7-248.e10.doi: https://doi.org/10.1016/j.jvoice.2016.07.025

34. Ilomäki I, Leppänen K, Kleemola L, Tyrmi J, Laukkanen A-M, Vilkman E. Relationships between self-evaluations of voice and working conditions, background factors, and phoniatric findings in female teachers. *Logopedics Phoniatrics Vocology.* 2009;34:20-31. doi: https://doi.org/10.1080/14015430802042013

35. Švec JG, Granqvist S. Guidelines for selecting microphones for human voice production research. *American Journal of Speech-Language Pathology.* 2010;19:356-368.doi: doi:10.1044/1058-0360(2010/09-0091)

36. Boersma P, Weenink D. Praat: Doing phonetics by computer. Amsterdam, the Netherlands: Institute of Phonetic Sciences, University of Amsterdam. 2013 http://www.fon.hum.uva.nl/praat/manual/sound_pressure_calibration.html

37. Švec JG, Granqvist S. Tutorial and Guidelines on Measurement of Sound Pressure Level in Voice and Speech. *Journal of Speech, Language, and Hearing Research.* 2018;61:441-461. doi:10.1044/2017_JSLHR-S-17-0095

38. Santos JRA. Cronbach's alpha: A tool for assessing the reliability of scales. *Journal of extension.* 1999;37:1-5. https://www.joe.org/joe/1999april/tt3.php

39. Hillenbrand JS. Version 1.56 [computer program], 2006. https://homepages.wmich.edu/~hillenbr/

40. Watts CR, Awan SN, Maryn Y. A comparison of cepstral peak prominence measures from two acoustic analysis programs. *Journal of Voice.* 2017;31: 387.e1–387.e10. doi: https://doi.org/10.1016/j.jvoice.2016.09.012

41. Maryn Y, Corthals P, Van Cauwenberge P, Roy N, De Bodt M. Toward improved ecological validity in the acoustic measurement of overall voice quality: combining continuous speech and sustained vowels. *Journal of voice.* 2010;24:540-555. doi: https://doi.org/10.1016/j.jvoice.2008.12.014

42. Latoszek BBv, De Bodt M, Gerrits E, Maryn Y. The exploration of an objective model for roughness with several acoustic markers. *Journal of Voice.* 2017;32:149-161.doi: https://doi.org/10.1016/j.jvoice.2017.04.017

43. Heman-Ackah YD, Sataloff RT, Laureyns G, et al. Quantifying the cepstral peak prominence, a measure of dysphonia. *Journal of voice.* 2014;28:783-788.doi:https://doi.org/10.1016/j.jvoice.2014.05.005

44. Balasubramanium RK, Karuppali S, Bajaj G, Shastry A, Bhat J. Acoustic-Perceptual Correlates of Voice in Indian Hindu Purohits. *Journal of Voice.* 2018. doi: https://doi.org/10.1016/j.jvoice.2018.03.006

45. Dejonckere PH, Bradley P, Clemente P, et al. A basic protocol for functional assessment of voice pathology, especially for investigating the efficacy of (phonosurgical) treatments and evaluating new assessment techniques. *European Archives of Oto-rhino-laryngology.* 2001;258:77-82.doi: https://doi.org/10.1007/s004050000299

46. Södersten M, Hertegård S, Hammarberg B. Glottal closure, transglottal airflow, and voice quality in healthy middle-aged women. *Journal of Voice.* 1995;9:182-197.doi: https://doi.org/10.1016/S0892-1997(05)80252-8

47. Sulter AM, Schutte HK, Miller DG. Standardized laryngeal videostroboscopic rating: differences between untrained and trained male and female subjects, and effects of varying sound intensity, fundamental frequency, and age. *Journal of Voice.* 1996;10:175-189. doi: https://doi.org/10.1016/S0892-1997(96)80045-2

48. Sulter A, Albers F. The effects of frequency and intensity level on glottal closure in normal subjects. *Clinical Otolaryngology.* 1996;21:324-327. doi: https://doi.org/10.1111/j.1365-2273.1996.tb01079.x

49. Awan SN, Giovinco A, Owens J. Effects of vocal intensity and vowel type on cepstral analysis of voice. *Journal of voice.* 2012;26: 670.e15–670.e20. doi: https://doi.org/10.1016/j.jvoice.2011.12.001

50. Chen G, Kreiman J, Shue Y-L, Alwan A. Acoustic correlates of glottal gaps. *Twelfth Annual Conference of the International Speech Communication Association. INTERSPEECH* 2011:2673-2676. https://www.isca-speech.org/archive/interspeech_2011/i11_2673.html

51. Chen G, Kreiman J, Gerratt BR, Neubauer J, Shue Y-L, Alwan A. Development of a glottal area index that integrates glottal gap size and open quotient. *The Journal of the Acoustical Society of America.* 2013;133:1656-1666. doi:https://doi.org/10.1121/1.4789931

52. Sundberg J, Gauffin J. Waveform and spectrum of the glottal voice source. *Speech Transmission Laboratory:Quarterly Progress and Status Reports.* 1978;19:35-50. https://pdfs.semanticscholar.org/4180/fe9a05b149e3b46625da62451b4d878f8451.pdf

53. Titze I. Principles of Voice Production (National Center for Voice and Speech, Iowa City, IA:). *Chap 9.* 2000:275.

54. Zheng Y-Q, Zhang B-R, Su W-Y, et al. Laryngeal aerodynamic analysis in assisting with the diagnosis of muscle tension dysphonia. *Journal of voice.* 2012;26:177-181. doi:https://doi.org/10.1016/j.jvoice.2010.12.001

55. Södersten M, Ternström S, Bohman M. Loud speech in realistic environmental noise: phonetogram data, perceptual voice quality, subjective ratings, and gender differences in healthy speakers. *Journal of Voice.*2005;19:29-46.doi: https://doi.org/10.1016/j.jvoice.2004.05.002

56. Rantala L, Vilkman E. Relationship between subjective voice complaints and acoustic parameters in female teachers' voices. *Journal of Voice.* 1999;13:484-495.doi: https://doi.org/10.1016/S0892-1997(99)80004-6

57. Schneider B, Bigenzahn W. Vocal risk factors for occupational voice disorders in female teaching students. *European Archives of Oto-Rhino-Laryngology and Head & Neck.* 2005;262:272-276. doi: https://doi.org/10.1007/s00405-004-0768-2