# Effects of vocal loading on the phonation and collision threshold pressures

*Laura Enflo[1], Johan Sundberg[1] and Friedemann Pabst[2]*
*[1]Department of Speech, Music & Hearing, Royal Institute of Technology, KTH, Stockholm, Sweden*
*[2]Hospital Dresden Friedrichstadt, Dresden, Germany*

## Abstract

*Phonation threshold pressures (PTP) have been commonly used for obtaining a quantitative measure of vocal fold motility. However, as these measures are quite low, it is typically difficult to obtain reliable data. As the amplitude of an electroglottograph (EGG) signal decreases substantially at the loss of vocal fold contact, it is mostly easy to determine the collision threshold pressure (CTP) from an EGG signal. In an earlier investigation (Enflo & Sundberg, forthcoming) we measured CTP and compared it with PTP in singer subjects. Results showed that in these subjects CTP was on average about 4 cm $H_2O$ higher than PTP. The PTP has been found to increase during vocal fatigue. In the present study we compare PTP and CTP before and after vocal loading in singer and non-singer voices, applying a loading procedure previously used by co-author FP. Seven subjects repeated the vowel sequence /a,e,i,o,u/ at an SPL of at least 80 dB @ 0.3 m for 20 min. Before and after the loading the subjects' voices were recorded while they produced a diminuendo repeating the syllable /pa/. Oral pressure during the /p/ occlusion was used as a measure of subglottal pressure. Both CTP and PTP increased significantly after the vocal loading.*

## Introduction

Subglottal pressure, henceforth $P_{sub}$, is one of the basic parameters for control of phonation. It typically varies with fundamental frequency of phonation F0 (Ladefoged & McKinney, 1963 & Cleveland & Sundberg, 1985). Titze (1992) derived an equation describing how the minimal $P_{sub}$ required for producing vocal fold oscillation, the phonation threshold pressure (PTP) varied with F0. He approximated this variation as:

$$PTP = a + b*(F0 / MF0)^2 \quad (1)$$

where PTP is measured in cm $H_2O$ and MF0 is the mean F0 for conversational speech (190 Hz for females and 120 Hz for males). The constant a = 0.14 and the factor b = 0.06.

Titze's equation has been used in several studies. These studies have confirmed that vocal fold stiffness is a factor of relevance to PTP. Hence, it is not surprising that PTP tends to rise during vocal fatigue (Solomon & DiMattia, 2000 & Milbrath & Solomon, 2003 & Chang & Karnell, 2004). A lowered PTP should reflect greater vocal fold stiffness, which is a clinically relevant property; high motility must be associated with a need for less phonatory effort for a given degree of vocal loudness.

Determining PTP is often complicated. One reason is the difficulty of accurately measuring low values. Another complication is that several individuals find it difficult to produce their very softest possible sound. As a consequence, the analysis is mostly time-consuming and the data are often quite scattered (Verdolini-Marston et al., 1990).

At very low subglottal pressures, i.e. in very soft phonation, the vocal folds vibrate, but with an amplitude so small that the folds never collide. If subglottal pressure is increased, however, vocal fold collision normally occurs. Like PTP, the minimal pressure required to initiate vocal fold collision, henceforth the collision threshold pressure (CTP), can be assumed to reflect vocal fold motility.

CTP should be easy to identify by means of an electroglottograph (EGG). During vocal fold contact, the EGG signal can pass across the glottis, resulting in a high EGG amplitude. Conversely, the amplitude is low when the vocal folds fail to make contact. In a previous study we measured PTP and CTP in a group of singers before and after vocal warm-up. The results showed that both PTP and CTP tended to drop after the warm-up, particularly for the male voices (Enflo & Sundberg, forthcoming). The purpose of the present study was to explore the potential of the CTP measure in female and male subjects before and after vocal loading.

## Method

### Experiment

Seven subjects, two female (F) and five male (M), were recruited as subjects. One female and one male were amateur singers, one of the males had some vocal training while the remaining subjects all lacked vocal training. Their task was to repeat the syllable [pa:] with gradually decreasing vocal loudness and continuing until voicing had ceased, avoiding emphasis of the consonant /p/. The oral pressure during the occlusion for the consonant /p/ was accepted as an approximation of Psub. The subjects repeated this task three to six times on all pitches of an F major triad that fitted into their pitch range. The subjects were recorded in sitting position in a sound treated booth.

Two recording sessions were made, one before and one after vocal loading. This loading consisted of phonating the vowel sequence /a,e,i,o,u/ at an SPL of at least 80 dB @ 0.3 m during 20 min. All subjects except the two singers reported clear symptoms of vocal fatigue after the vocal loading.

Audio, oral pressure and EGG signals were recorded, see Figure 1. The audio was picked up at 30 cm distance by a condenser microphone (B&K 4003), with a power supply (B&K 2812), set to 0 dB and amplified by a mixer, DSP Audio Interface Box from (Nyvalla DSP). Oral pressure was recorded by means of a pressure transducer (Gaeltec Ltd, 7b) which the subject held in the corner of the mouth. The EGG was recorded with a two-channel electroglottograph (Glottal Enterprises EG 2), using the vocal fold contact area output and a low frequency limit of 40 Hz. This signal was monitored on an oscilloscope. Contact gel was applied to improve the skin contact. Each of these three signals was recorded on a separate track of a computer by means of the Soundswell Signal Workstation$^{TM}$ software (Core 4.0, Hitech Development AB, Sweden).

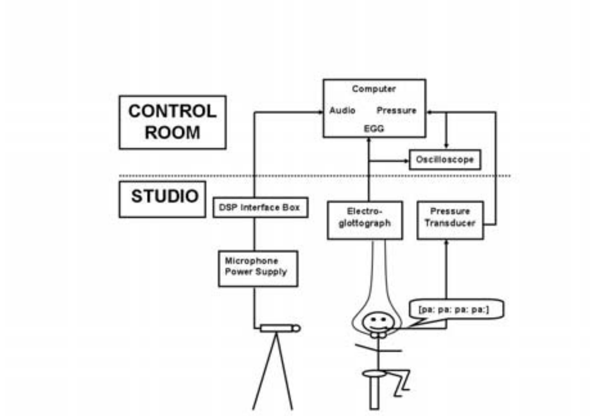


Figure 1: Experimental setup used in the recordings.

The audio signal was calibrated by recording a synthesized vowel sound, the sound pressure level (SPL) of which was determined by means of a sound level recorder (OnoSokki) held next to the recording microphone. The pressure signal was calibrated by recording it while the transducer was (1) held in free air and (2) immersed at a carefully measured depth in a glass cylinder filled with water.

### Analysis

The analysis was performed using the Soundswell Signal Workstation. As the oral pressure transducer picked up some of the oral sound, this signal was LP filtered at 50 Hz.

After a 90 Hz HP filtering the EGG signal was full-wave rectified, thus facilitating amplitude comparisons. Figure 2 shows an example of the signals obtained.

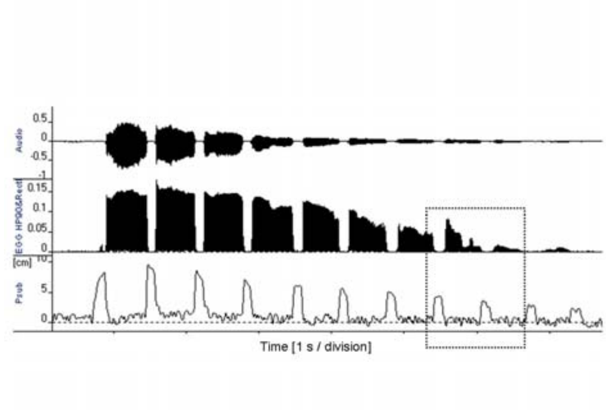


Figure 2: Example of the recordings analyzed showing the audio, the HP filtered and rectified EGG and the oral pressure signals (top, middle and bottom curves). The loss of vocal fold contact, reflected as a sudden drop in the EGG signal amplitude, is marked by the frame in the EGG and pressure signals.

As absence of vocal fold contact produces a great reduction of the EGG signal amplitude, such amplitude reductions were easy to identify in the recording. The subglottal pressures appearing immediately before and after a sudden amplitude drop were assumed to lie just above and just below the CTP, respectively, so the average of these two pressures was accepted as the CTP. For each subject, CTP was determined in at least three sequences for each pitch and the average of these estimates was calculated. The same method was applied for determining the PTP.

## Results

Both thresholds tended to increase with F0, as expected, and both were mostly higher after the loading. Figure 3 shows PTP and CTP before and after vocal loading for one of the untrained male subjects. The variation with F0 was less evident and less systematic for some subjects.

Table 1 lists the mean and SD across F0 of the after-to-before ratio for the subjects. The F0 range produced by the subjects was slightly narrower than one and a half octave for the male subjects and two octaves for the trained female but only 8 semitones for the untrained female. The after-to-before ratio for CTP varied between 1.32 and 1.06 for the male subjects. The corresponding variation for PTP was 1.74 and 0.98. The means across subjects were similar for CTP and PTP. Vocal loading caused a statistically significant increase of both CTP and PTP (paired samples t-test, $p<0.001$). Interestingly, the two trained subjects, who reported minor effects of the loading, showed small ratios for both CTP and PTP.

## Discussion

To our knowledge this is the first attempt to analyze the CTP in untrained voices. Hence, it is relevant to compare this threshold with the as yet commonly used PTP.

First, CTP appears to be a more reliable measure than PTP. In our previous investigation of the thresholds in singer subjects, repeated measurements showed that the ratio between the SD and the average tended to be smaller for the CTP than for the PTP (Enflo & Sundberg, forthcoming). Thus, in this respect, the CTP is a more reliable measure.

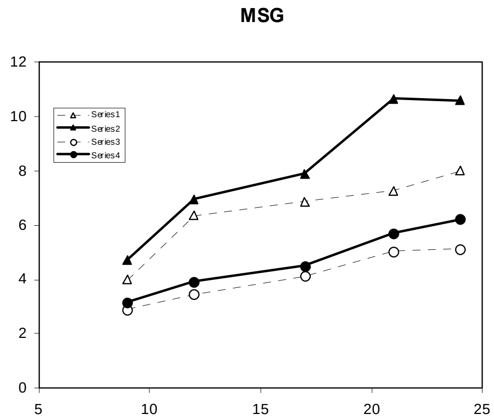


Figure 3: PTP (circles) and CTP (triangles) values in cm $H_20$ for one of the untrained male subjects. The graph shows threshold pressures before (dashed lines) and after (filled lines) vocal loading. Semitones relative C2 are used as seen on the x-axis.

Table 1. F0 range in semitones (Range), and mean after-to-before ratio and SD across F0 for the CTP and PTP for the male and female subjects. Letters U and T refer to untrained and trained voices, respectively.

| | Range | CTP | | PTP | |
|---|---|---|---|---|---|
| *Males* | st | Mean | SD | Mean | SD |
| MAG U | 17 | 1.32 | 0.10 | 1.13 | 0.32 |
| MES U | 17 | 1.06 | 0.04 | 1.02 | 0.11 |
| MDE U | 12 | 1.20 | 0.17 | 1.74 | 0.09 |
| MSG U | 16 | 1.24 | 0.15 | 1.13 | 0.05 |
| MJS T | 15 | 1.07 | 0.13 | 0.98 | 0.03 |
| ***Mean*** | | ***1.18*** | ***0.12*** | ***1.20*** | ***0.12*** |
| | | | | | |
| *Females* | | | | | |
| FAH U | 8 | 1.49 | 0.14 | 1.62 | 0.07 |
| FLE T | 24 | 1.08 | 0.13 | 1.06 | 0.15 |
| ***Mean*** | | ***1.29*** | ***0.13*** | ***1.34*** | ***0.11*** |

Second, the CTP seems easier to measure than the PTP. Most of our subjects found it difficult to continue reducing vocal loudness until after phonation had ceased. For determining CTP, it is enough that the vocal loudness is reduced to extremely soft phonation. This may be particularly advantageous when dealing with untrained and pathological voices.

A relevant aspect is to what extent the CTP provides the same information as PTP. Both should reflect the motility of the vocal folds, i.e., an important mechanical characteristic, as mentioned before. In our previous study with singer subjects we found that manipulating a and b in Titze's PTP equation (Eq. 1) yielded rather good approximations of the average CTP before and after warm-up. However, the untrained subjects in the present experiment showed an irregular variation with F0, so approximating their CTP curves with modified versions of Titze's equation seemed pointless.

A limitation of the CTP is that, obviously, it cannot be measured when the vocal folds fail to collide. This often happens in some dysphonic voices in the upper part of the female voice range, and in male falsetto phonation.

The main finding of the present investigation was that CTP increased significantly after vocal loading. For the two trained subjects, the effect was minimal, and these subjects did not experience any vocal fatigue after the vocal loading. On average, the increase was similar for CTP and PTP. This supports the assumption that CTP reflects similar vocal fold characteristics as the PTP.

Our results suggest that the CTP may be used as a valuable alternative or complementation to the PTP, particularly in cases where it is difficult to determine the PTP accurately.

## Conclusions

The CTP seems a promising alternative or complement to the PTP. The task of phonating at phonation threshold pressure seems more difficult for subjects than the task of phonating at the collision threshold. The information represented by the CTP would correspond to that represented by the PTP. In the future, it would be worthwhile to test CTP in other applications, e.g., in a clinical setting with patients before and after therapy.

## Acknowledgements

The kind cooperation of the subjects is gratefully acknowledged. This is an abbreviated version of a paper which has been submitted to the Interspeech conference in Brighton, September 2009.

## References

Chang A. and Karnell M.P. (2004) Perceived Phonatory Effort and Phonation Threshold Pressure Across a Prolonged Voice Loading Task: A Study of Vocal Fatigue. J Voice 18, 454-66.

Cleveland T. and Sundberg J. (1985) Acoustic analyses of three male voices of different quality. In A Askenfelt, S Felicetti, E Jansson, J Sundberg, editors. SMAC 83. Proceedings of the Stockholm Internat Music Acoustics Conf, Vol. 1 Stockholm: Roy Sw Acad Music, Publ. No. 46:1, 143-56.

Enflo L. and Sundberg J. (forthcoming) Vocal Fold Collision Threshold Pressure: An Alternative to Phonation Threshold Pressure?

Ladefoged P. and McKinney NP. (1963) Loudness, sound pressure, and subglottal pressure in speech. J Acoust Soc Am 35, 454-60.

Milbrath R.L. and Solomon N.P. (2003) Do Vocal Warm-Up Exercises Alleviate Vocal Fatigue?, J Speech Hear Res 46, 422-36.

Solomon N.P. and DiMattia M.S. (2000) Effects of a Vocally Fatiguing Task and Systematic Hydration on Phonation Threshold Pressure. J Voice 14, 341-62.

Titze I. (1992) Phonation threshold pressure: A missing link in glottal aerodynamics. J Acoust Soc Am 91, 2926-35.

Verdolini-Marston K., Titze I. and Druker D.G. (1990) Changes in phonation threshold pressure with induced conditions of hydration. J Voice 4, 142-51.