Threshold Pressure For Vocal Fold Collision

Laura Enflo
Department of Speech, Music and Hearing
KTH, Royal Institute of Technology

Abstract

Phonation threshold pressure (PTP) is frequently used for characterizing vocal fold vibration properties. However, because of the very low pressures, it is often difficult to measure PTP with acceptable accuracy. This investigation analyses an alternative pressure, the collision threshold pressure (CTP), defined as the lowest pressure required to initiate vocal fold collision. Fourteen amateur singers – six female and eight male – served as subjects. They were recorded while repeating the syllable /pa:/ with a gradually decreasing degree of vocal loudness. Several pitches were recorded before and after vocal warm-up by means of an audio microphone, an electroglottograph (EGG) and a pressure transducer, which the subjects held in the corner of their mouths and which hence reflected oral pressure. The amplitude of an EGG signal increases substantially when the vocal folds make contact, i.e., collide, thus allowing simple measurement of the CTP. The oral pressure during the p-occlusion was used as for estimating subglottal pressure. CTP and PTP tended to be higher before than after the warm-up, although the differences varied greatly both between given subject's pitches and between subjects. Repeated measurements on two subjects showed lower standard deviations for CTP than for PTP. The results support the conclusion that CTP is a promising parameter in investigations of vocal fold characteristics.

Introduction

A low value on the *phonation threshold pressure* (PTP), i.e. the minimal lung pressure required to initiate and sustain vocal fold oscillation, is assumed to correspond to physiologically more efficient phonation and reduced phonatory effort. PTP measurements have been assumed to have many potential areas of use.

In 1988, Titze derived an equation based on theory that showed how PTP increases with pitch as the vocal-fold thickness decreases. He applied this equation to results from models, and found that the best fit was obtained in using an equation with the following constants (Titze, 1991):

Equation 1: $PTP = 0.14 + 0.06(F_0 / F_{M0})^2$

where PTP is measured in cm H_2O, F_0 is the fundamental frequency and F_{M0} is the mean value for conversational speech (190 Hz for females and 120 Hz for males). The same mean values have been used for singing as well (Elliot, Sundberg & Gramming, 1995).

Unfortunately, the measurement of PTP is complicated by the difficulty for human beings to produce the softest possible sound. As a consequence, the values of PTP measurements are often reduced by a wide scatter. For this reason, it is desirable to find a better measure of subglottal pressure of relevance to vocal fold properties.

Collision Threshold Pressure

For very low subglottal pressures, i.e. in very soft phonation, the vocal folds fail to reach contact. The folds vibrate, but with an amplitude so small that the folds never collide. If the subglottal pressure is increased, however, vibration amplitude is increased such that the folds start to collide. The minimal pressure required to initiate vocal fold collision, henceforth the *collision threshold pressure* (CTP), is a new measure which seemed likely to be related to vocal fold properties. Being higher than the PTP, it seemed possible that subjects would find it easier to intentionally produce and replicate CTP than PTP and, hence, that it could be determined with a higher accuracy.

Vocal Warm-Up

Many singers prefer to warm up their voices before singing, both professionals (Fleming, 2005 & Nilsson, 1995) and amateurs. Vocal warm-up is considered helpful for singers in order to use their whole voice and to avoid injuries while singing. A pilot study (Elliot et al, 1995) showed that there is a significant difference in the PTP level before and after the voice has been warmed up. However, the results differed from subject to subject and failed to provide a definitive answer to the question if a vocal warm-up really lowers the PTP. The purpose of the present investigation was to explore the new measure, partly by trying to determine if vocal warm-up lowers the CTP.

Method

Fourteen subjects, six female and eight male, were recorded while repeating the syllable [pa:] in a decrescendo on each pitch, starting at medium loudness and continuing until voicing ceased. All of the subjects were amateur singers with a considerable amount of vocal training. Each subject was recorded twice: before and after vocal warm-up. The subjects warmed up their voices according to their own habitual procedures, without instructions from the experimenter. Every subject felt warmed up before the second recording.

To obtain an estimate of reproducibility of the PTP and CTP measuring methods two of the subjects, one female and one male, were recorded on three different occasions.

The recordings were made on three channels: audio, EGG and subglottal pressure. Electro-glottography (EGG) was used to identify vocal fold collision. When the vocal folds are closed, the EGG signal can pass, such that the amplitude is high, and when the glottis is open, the amplitude is low.

The recordings were made in a studio with the subject sitting on a chair with the electroglottograph tied around his/her neck, holding a catheter provided with a pressure transducer in the corner of his/her mouth. The distance from the subject's mouth and the microphone was 30 cm. Each pitch was chosen according to the normal voice range of each subject, and was given to the subjects from a singing synthesizer program (Madde). Each [pa:]-sequence was repeated three to six times, in order to obtain at least three measurable sequences.

CTP was determined for each tone as sung by each subject. Three pressure values of the CTP were obtained. These values were identified with the aid of the EGG signal. For PTP, only one pressure value could be collected per pitch for every subject. The reason was that in many cases the subjects stopped repeating the syllable [pa:] before voicing ceased.

The analysis was performed using the Soundswell Signal Workstation™ and all computations were done with Microsoft Excel.

The pitches were measured and expressed in the logarithmic semitone unit, thus facilitating comparison between male and female subjects. The tone C2 was used as reference. In the following graphs, subglottal pressure was also plotted using a logarithmic scale.

Results and Discussion

As expected, CTP showed higher values than the PTP, regardless of pitch and subjects. Thus, CTP-PTP > 0 for both females and males.

The warm-up effect, although considerable, varied greatly between pitches and subjects, both concerning CTP and PTP (see figure 1, 2, 3 & 4 below). Paired *t*-tests showed that there was a significant difference between the CTP values before and after vocal warm-up for each pitch for all males (p=0.99) and a not significant difference for all females (p=0.72). The corresponding probability values for PTP were significant for all females (p=0.97) and not significant for all males (p=0.55).

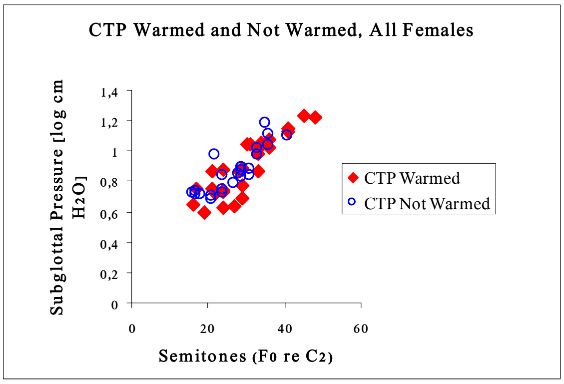

Figure 1. The CTP for all females individually and for each pitch, before and after vocal warm-up.

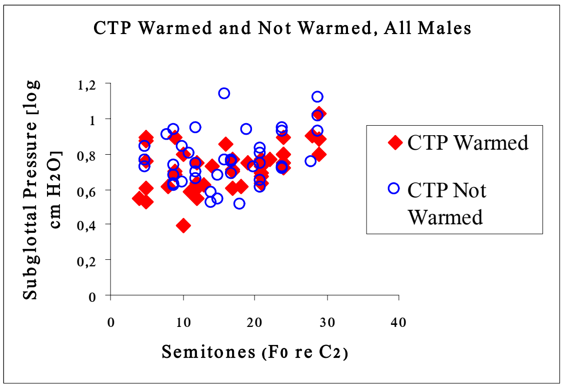

Figure 2. The CTP for all males individually and for each pitch, before and after vocal warm-up.

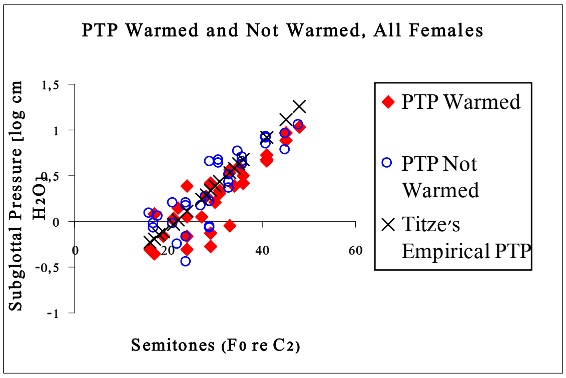

Figure 3. The PTP for all females individually and for each pitch, before and after vocal warm-up.

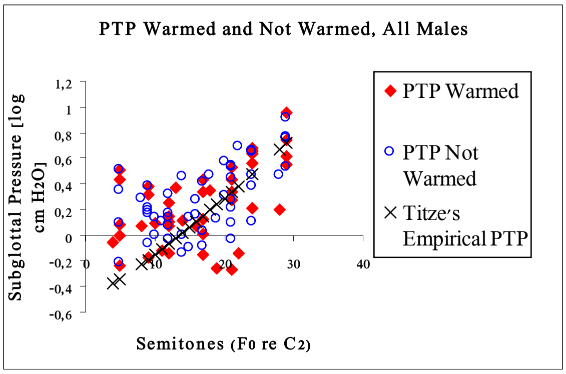

Figure 4. The PTP for all males individually and for each pitch, before and after vocal warm-up.

Two female subjects (EF3 and LF1 rec 3) and one male (JM2 rec 2) had to be eliminated from analysis. The main reason for this was because the catheter provided with a pressure transducer accidentally moved into a position between the lips, thus causing noise.

Reproducibility

The standard deviations for CTP were computed for all subjects and the standard deviations for PTP were calculated for JM2 and LF1, who each had comparable data from two of the three recording sessions (Figure 5 & 6). All standard deviation values in the plots are mean values of the standard deviations for each pitch and each subject.

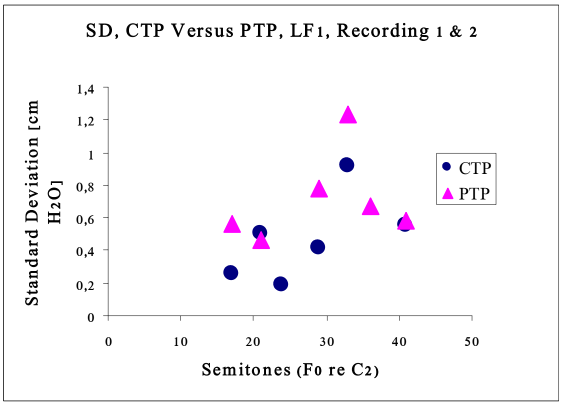

Figure 5. Female subject LF1: Standard deviation for CTP and PTP, respectively.

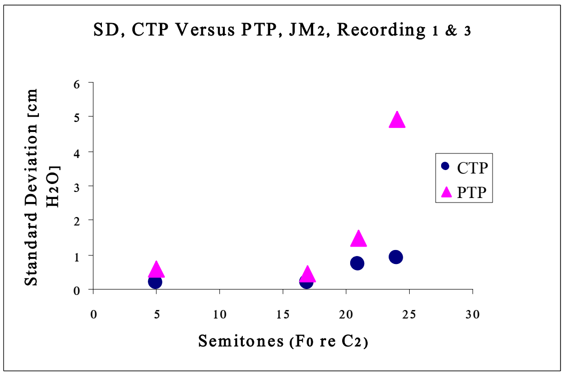

Figure 6. Male subject JM2: Standard deviation for CTP and PTP, respectively.

Two-sample, heteroscedastic *t*-tests showed the probability that the subglottal pressure values for the two compared recordings for each of the subjects JM2 and LF1 would be the same for each pitch (see Table 1).

Table 1. The probability that the subglottal pressure values from the two compared recordings (i.e. two sets of subglottal pressure values) for each subject and pitch would be equal.

Subjects	**CTP before v w-u**	**CTP after v w-u**	**PTP before v w-u**	**PTP after v w-u**
JM2	0.68	0.24	0.57	0.77
LF1	0.80	0.79	0.82	0.03

In view of the fact that there were not enough PTP values available for calculating the standard deviations for all subjects, only the standard deviations for the CTP were checked for all females and males, respectively. The standard deviations for LF1 and JM2 did not differ much from the standard deviations for the other subjects.

It seems that CTP could be determined with lower standard deviation values than PTP. Even when taken into account the fact that the CTP values come from a greater number of measured points, this could not completely explain why the standard deviation is lower for CTP. In a previously mentioned study (Elliot et al, 1995) where only PTP was measured, the differences between the PTP values and Titze’s empirical values (Equation 1) were calculated for all pitches pooled and a table with the average values, including the standard deviations, were included in the report. The values for all of the subjects in the present study were calculated in the same way and compared with the older data, to check if they were similar, and if the new PTP values for this reason could be worthy of a comparison with the CTP values (see Table 2).

Table 2. The mean difference and the standard deviation of the mean difference between the measured PTP values and Titze’s theoretical PTP values before and after vocal warm-up for females and males. New data compared with previously published values. All pitches included.

Subjects pooled ***Measurement in this work***	**Before vocal warm-up** (cm H2O)	**After vocal warm-up** (cm H2O)
Females		
Mean	0.9	1.3
SD	0.9	1.2
Males		
Mean	0.9	1.0
SD	0.8	0.7
Measurement from 1995		
Females		
Mean	1.9	1.7
SD	2.0	1.5
Males		
Mean	1.4	1.8
SD	1.1	1.1

Conclusions and Further Work

Measurements indicate that the standard deviation for the CTP is lower than for the PTP. Another advantage of the CTP method for measuring subglottal threshold pressure is that it is less time-consuming to measure than the PTP method. However, the PTP method is more reliable at high pitches since the larynx height and the falsetto singing are problematic when measuring the CTP.

The effect of vocal warm-up is considerable for all subjects, but with a high between-subject variability. Clear instructions to the subjects are important in order to prevent a lack of PTP values below the threshold and to avoid unrealistic pressure values caused by misplacements of the catheter provided with a transducer.

Further research is necessary to find out whether these indications about CTP are correct. The sample of fourteen subjects is too small to allow conclusions.

Acknowledgments

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