Collision Threshold Pressure Before and After Vocal Loading

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Abstract

The phonation threshold pressure (PTP) has been found to increase during vocal fatigue. In the present study we compare PTP and collision threshold pressure (CTP) before and after vocal loading in singer and non-singer voices. 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 this 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.

Index Terms: collision threshold pressure, phonation threshold pressure, vocal fatigue, vocal loading.

1. Introduction

Subglottal pressure, henceforth Psub, is one of the basic parameters for control of phonation. It typically varies with fundamental frequency of phonation F0 (1, 2). Titze (3) derived an equation describing how the minimal Psub required for producing vocal fold oscillation varied with F0. The variation with F0 of this phonation threshold pressure (PTP) can be approximated as:

\[ PTP = a + b(F0 / MF0)^2 \]  

where PTP is measured in cm H2O 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. Experimental support was recently established from a mechanical replica of the vocal folds (4). Garrell and associates (5) predicted the dependence on F0 from a vocal fold vibration model based on the so-called relaxation oscillation principle. In addition, their model could explain why PTP varies depending on vocal fold stiffness. Zhang and co-workers (6) developed a body-cover vocal fold model and examined how the body-cover stiffness ratio affected the PTP. They found that PTP first increased and then reached a plateau. Solomon and co-workers (7) measured PTP in untrained female and male voices. They found that the values of the constant and the factor coefficient varied between individuals, a finding which may reflect differences in e.g., degree of glottal adduction. Chan and Titze (8) tested a linear tract impedance and increased with viscous shear modulus or dynamic viscosity of the vocal fold cover.

The above results show that vocal fold stiffness is a factor of relevance to PTP. Hence, it is not surprising that PTP tends to rise during vocal fatigue (9, 10, 11). Solomon and associates (7) observed that the minimum PTP occurred at the subject’s most comfortable pitch. Motel and collaborators (12) studied the effects of vocal warm-up in sopranos and found that PTP increased at high, but not for low and comfortable F0. McHenry and associates, however, (13) observed that after warm-up the PTP was significantly lowered in females, but not in males. 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 associated with problems. One reason is the difficulty of accurately measuring low values; an accuracy of measurements amounting to 1 cm H2O represents a 50% error of a 2 cm H2O PTP. 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 (14).

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 from one fold to the other, such that the EGG amplitude is high. 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 (15). 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.

2. Method

2.1. 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 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. These pitches were presented to the subjects, one by one, on a synthesizer. The subjects were recorded in sitting position in a sound treated booth.
Two recording sessions were made, one before and one after vocal loading. The vocal 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, a procedure previously used by co-author FP. 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 electromyograph (Glottal Enterprises EG 2), using the vocal fold contact area (VFCA) 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™ software (Core 4.0, Hitech Development AB, Sweden).

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. This SPL value was announced on the recording. 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. Also, this depth was announced on the recording.

2.2. Analysis

The analysis was performed using the Soundswell Signal Workstation™ (Soundswell Core™ 4.0, Hitech Development AB, Sweden). As the oral pressure transducer picked up some of the oral sound, this signal was LP filtered at 50 Hz.

The EGG signal was processed in two steps. First, noise was eliminated by a 90 Hz HP filter. Then, the signal was full-wave rectified, thus facilitating amplitude comparisons. Figure 2 shows an example of the signals obtained.

The CTP value was identified with the aid of the EGG signal. 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 steep decrease of the EGG amplitude were regarded as lying just above and just below the CTP, respectively. Then, for each sequence, the average was calculated of these two pressure values. This average 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.

3. Results

Some untrained subjects had difficulties with producing a great variation of F0. 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 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 CTP varied between 1.32 and 1.06 for the male subjects. The corresponding variation of PTP was 1.74 and 0.98. The means across subjects were similar for CTP and PTP. Vocal loading causes an increase for both CTP and PTP. This increase was statistically significant (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.
Clinical setting. Advantageous when dealing with untrained voices, e.g., in a clinical setting. It is enough that the vocal loudness is reduced to extremely soft phonation. This may be particularly determining the CTP, it is enough that the vocal loudness is reduced until phonation ceased. When determining the CTP, it is enough that the vocal loudness is reduced to extremely soft phonation. This may be particularly advantageous when dealing with untrained voices, e.g., in a clinical setting.

A relevant aspect is to what extent the CTP provides an advantageous 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.

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.

### 5. 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.

### 6. Acknowledgements

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### 7. References


