

Relationship Between Subglottal Pressure and Sound Pressure Level in Untrained Voices

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Summary: Objectives. Subglottal pressure (P_s) is strongly correlated with sound pressure level (SPL) and is easy to measure by means of commonly available equipment. The SPL/ P_s ratio is strongly dependent on the efficiency of the phonatory apparatus and should be of great relevance to clinical practice. However, published normative data are still missing.

Method. The subjects produced sequences of the syllable [pæ], and P_s was measured as the oral pressure during the [p] occlusion. The P_s to SPL relationship was determined at four pitches produced by 16 female and 15 male healthy voices and analyzed by means of regression analysis. Average correlation between P_s and SPL, average SPL produced with a P_s of 10 cm H₂O, and average SPL increase produced by a doubling of P_s were calculated for the female and for the male subjects. The significance of sex and pitch conditions was analyzed by means of analysis of variance (ANOVA).

Results. Pitch was found to be an insignificant condition. The average correlation between P_s and SPL was 0.83 and did not differ significantly between the female and male subjects. In female and male subjects, $P_s = 10$ cm H₂O produced 78.1 dB and 80.0 dB SPL at 0.3 m, and a doubling of P_s generated 11.1 dB and 9.3 dB increase of SPL. Both these gender differences were statistically significant.

Conclusions. The relationship between P_s and SPL can be reliably established from series of repetitions of the syllable [pæ] produced with a continuously changing degree of vocal loudness. Male subjects produce slightly higher SPL for a given pressure than female subjects but gain less for a doubling of P_s . As these relationships appear to be affected by phonation type, it seems possible that in the future, the method can be used for documenting degree of phonatory hypofunction and hyperfunction.

Key Words: Subglottal pressure–SPL–Female and male voices.

INTRODUCTION

Subglottal pressure (P_s) is known to be a strong predictor of sound pressure level (SPL).¹ Moreover, it can be assumed that the relationship between the two represents an important aspect of phonation efficiency and thus would be clinically relevant; a voice producing a low SPL with a given P_s is likely to need to spend more effort than a voice that obtains a higher SPL for the same P_s . Because the logarithm of P_s mostly shows a linear relationship with SPL, the relationship between them can be quantized in terms of an equation representing the trend line. This relationship has been analyzed in several studies.^{2,3} It possesses two relevant characteristics, its intercept, for example, the SPL obtained for a given P_s value, and its slope, for example, the SPL increase produced by a doubling of P_s .

Several methods have been used for measuring P_s . A direct method is by inserting a needle through the trachea. This method has been used in few studies, presumably because of its invasive nature. For the same reason, several alternative methods have been developed. Schutte³ measured the pressure in an esophageal balloon, which he compensated for lung volume. In the study by Tanaka and Gould,⁴ P_s was measured indirectly by means of body plethysmograph. The most common

method is to estimate P_s from the intraoral pressure during [p] occlusion.^{5–8}

Schutte³ analyzed airflow, P_s , and SPL in 63 healthy voices and 67 patients suffering from various voice pathologies. He found a great interindividual scatter of the SPL obtained for a given P_s . This was also noted by Sundberg et al.⁶ On the other hand, Tanaka and Gould⁴ found a rather small interindividual variation of the relationship between flow, P_s , and SPL in an investigation of 10 healthy voices, thus suggesting that the P_s to SPL relationship is clinically useful. For the dysphonic voices, Schutte³ noted that a given P_s produced lower SPL values than for the healthy voices. Gramming⁹ made a similar observation for 10 female and 10 male patients suffering from nonorganic dysphonia. This is a strong support for the previously mentioned assumption that the relationship between P_s and SPL is clinically relevant.

The slope of the trend line is another measure of potential clinical relevance. This parameter can be quantized in terms of the SPL gain generated by a doubling of P_s . Schutte³ found that in healthy voices, a doubling of P_s yielded an average SPL increase of 10 dB for women and 9 dB for men. Similar results have been found in subsequent studies; 9 dB by Tanaka and Gould,⁴ 10 dB by Sundberg et al.,^{6,10} whereas 13 dB was reported by Holmberg et al.⁷

Prior studies have found that the doubling of P_s may be affected by whether the speaker is male or female. Thus, Schutte³ noted that a doubling in P_s produced a 10-dB increase of SPL in female voices and a 9-dB increase in male voices. After the study by Schutte, this sex difference has not been studied in great detail. Hence, although the difference he observed was small, it cannot be excluded that sex is a relevant factor for normative data on the P_s /SPL relationship.

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Other factors of potential relevance to this relationship are vowel and F_0 . Plant and Younger¹¹ studied the relationship between F_0 , P_s , and SPL in the syllables [pa] and [i] as produced by nine men with healthy voices. Individual variation was considerable, but they noted that around a certain F_0 , changes in P_s had a particularly large impact on SPL in many participants. This is not surprising. SPL mostly equals the SPL of the strongest spectrum partial, the amplitude of which is heavily influenced by its frequency distance to the first formant (F_1).¹² F_1 for the vowel [i] lies in the vicinity of 250 Hz, so that for an F_0 near 110 Hz, the second partial would be quite close to F_1 . Thus, vowel quality and F_0 should play an important role in the P_s /SPL relationship and must be taken into account in an attempt to create normative data. Also, limiting data to one single vowel is preferable.

Summarizing, the P_s /SPL relationship has been analyzed in several earlier studies but mostly with few subjects or few P_s values. As this relationship seems relevant to voice function, it seemed worthwhile to analyze it in greater detail. Thus, the aim of the present study was to examine this relationship on a larger sample, with controlled F_0 , sex and vowel quality, and over a wide P_s range.

METHOD

Sixteen women between 26 and 36 years (Mean, 29 years; standard deviation [SD], 3 years) and 15 men between 25 and 47 years (Mean, 29 years; SD, 6 years) volunteered as subjects. Inclusion criteria were age <50 years and no reported voice problems at the time of the study. Most subjects had none or only a modest experience of singing.

The subjects were asked to repeatedly pronounce sequences of the syllable [pæ] with a gradually increasing or decreasing degree of vocal loudness that ranged from the loudest to the softest possible. They were asked to keep F_0 constant. They produced four such sequences at four pitches, equally spaced within one octave, 175, 220, 277, and 350 Hz for women and 110, 138, 175, and 220 Hz for men, that is, in the normal ranges for the female and the male speech. The vowel [æ] was chosen because F_1 is far above the highest F_0 analyzed.

Oral pressure during the [p] occlusions was measured by a pressure transducer (Glottal Enterprises 162, Syracuse, NY) attached to a thin plastic tube, inner diameter 4 mm, that the subjects held in the corner of their mouths. The pressure signal was sent to a sound card (TEAC RD 200 PCM, US Instrument Services, Southlake, TX) and recorded in the Soundswell program. It was calibrated by recording pressure values measured by means of a manometer; the pressure values were announced on the recording.

The audio signal was recorded with a headset microphone (DPA 4066-C, DPA Microphones A/S, Allerød, Denmark) at a measured distance of 12 cm from the mouth. The microphone was attached to a preamp (Symetrix SX202, Symetrix Inc., W. Lynnwood, WA) and the signal was sent to sound card (TEAC RD 200 PCM) and recorded in the Soundswell program. Calibration of SPL was made in each recording session by sustaining a vowel sound, the SPL of which was measured by a

sound level meter (Ono Sokki LA 210, Yokohama, Japan) at the recording microphone; measured SPL value was announced in recording.

ANALYSIS

The calibrations of SPL and intraoral pressure were copied into the end of each recorded file, and the recorded intraoral pressure voltage was calibrated using the Swellcal module in the Soundswell program.

A prerequisite of reliable values of the intraoral pressure is that the pressure signal reaches a plateau during the [p] occlusion.¹³ Tilting pressure peaks, indicating a changing intraoral pressure during the [p] occlusion, were discarded. The pressure value was taken from a point in time when the pressure signal showed a plateau.

Intraoral pressure and time for each [pæ] syllable were extracted to an excel spreadsheet. SPL data were extracted to a separate file in Soundswell. In each syllable, the mean SPL was measured during first half of the vowel by means of the histogram module of the Soundswell program and was extracted to the spreadsheet together with its time coordinate. In this way, pairs of estimated P_s values and SPL values were obtained.

In some cases, the subject changed the pitch substantially with vocal loudness. Therefore, the pitch of each syllable was controlled. In the case of 34 of the 1513 syllables recorded, F_0 was >1 semitone off the intended value. These cases were discarded.

STATISTICAL ANALYSIS

SPL mostly showed a logarithmic relationship to P_s . Figure 1 shows a typical example. Thus, the relationship could be approximated with an equation of the type

$$\text{SPL} = k \times \log(P_s) + I$$

where k and I are constants.

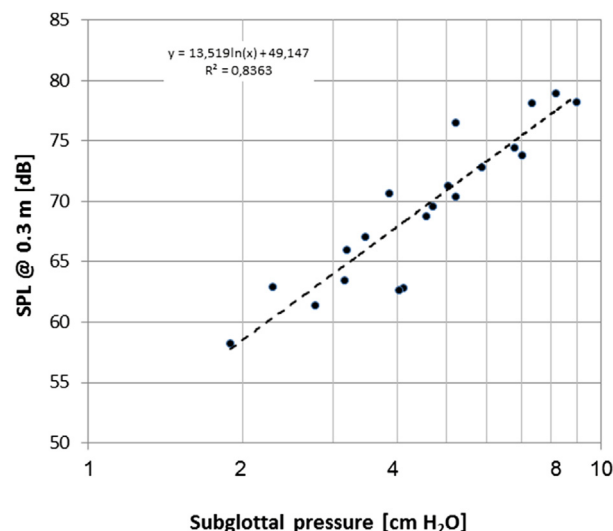


FIGURE 1. Typical example of the relationship between subglottal pressure and sound pressure level (SPL). The equation refers to the trend line (dashed).

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