The effects of frequency and intensity level on glottal closure in normal subjects

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INTRODUCTION

Vocal sound is based on the cyclical opening and closing of the vocal folds. In this cycle the vocal folds are closed along a part of their length during a certain period. The degree of glottal closure is associated with voice quality and has a perceptive relationship with breathiness (1). Observations on the degree of glottal closure therefore enable a quantitative judgment of the vocal apparatus.

Quantitative data on glottal closure are needed to establish more adequate and complete information of the voice quality. In this investigation a large group of normal men and women was examined with videolaryngostroboscopy to produce standard values. As sound intensity and, to a lesser degree, frequency have been shown to have an effect on glottal closure, the influence of these variables was also investigated (1). Finally differences between men and women were analyzed.

METHODS

Subjects

To obtain information on glottal closure a group of 92 women and 47 men with neither vocal complaints nor vocal abnormality were examined. The mean age for the women was 20.3 years, ranging from 17 to 44, while the mean age
for the men was 25.0 years, ranging from 17 to 35.

Instrumentation

Laryngeal examinations were performed with a Wolf 90° rigid endoscope (Model 4450.57). A Brüel & Kjær 4914 Rhino-Larynx Stroboscope was used for stroboscopic investigation. The endoscope was connected to a Panasonic CCD camera (Model WV-CD 110E). Images were recorded on a Sony Betamax videorecorder SL-C9 E5 PAL. All laryngeal videostroboscopic examinations were performed by an experienced phoniatrian.

Procedure

Prior to the actual examination topical anaesthesia (Xylocaine®) was administered to all subjects. The endoscope was introduced into the oropharynx carefully so as not to touch any (oro-)pharyngeal structures to avoid gagging, as well as preventing the lens from smearing. Once focused on the vocal folds the video recording was started and the subject was asked to perform a set of phonatory tasks.

Phonatory tasks

The tasks consisted of the production of an /i/-like vowel sound at three intensities (comfortable, soft, loud) with three different pitches (comfortable, low, high). The intensity and pitch were chosen by the subject with the investigator's approval. Allowing the subject to choose the pitch and intensity level presumably resulted in a naturally comfortable voice production, hereafter referred to as "normal". Subjects were encouraged to produce an /i/-like vowel sound, to optimize the view of the larynx by obtaining a maximal anterior position of the cranial part of the epiglottis. Starting with normal intensity and pitch, each subject was asked to produce sounds with relatively soft, followed by relatively loud intensity, repeating this procedure with relatively low and high pitch. Care was taken to avoid transition from chest to falsetto register; however, in a number of women phonation in a falsetto voice could not be avoided.
Glottal closure rating

Vocal fold closure can be scored as a percentage. Figure 1 gives a schematized larynx with delineated vocal folds and incomplete glottal closure. The percentage of closure in this case is 65%.

Three observers, familiar with laryngostroboscopic video recordings, observed the acquired material and noted a percentage of closure for each recording. Each recording was played in slow-motion at 1/10 speed for observation of the most closed phase of the glottal cycle and to have enough time to complete the scoring.

The intensity and pitch level of each recording were determined and the fundamental frequency in hertz was determined by imitating the pitch produced and reading the output on an electroglottograph frequency counter.

At the end of the rating experiment 36 recordings were rated again to provide re-test data, and an intra-observer reliability was calculated.

The original scores of the judges and the re-test scores were used to calculate inter- and intra-observer reliability levels, respectively. The averaged scores on scales were used for descriptive statistics. To determine the effect of intensity and frequency level, as well as gender, analysis of variance was performed. If a significant interaction was present between factors, separate ANOVA's were performed on each factor level. Probability levels below $p<0.05$ were regarded as significant.

RESULTS

Laryngostroboscopic examinations resulted in 542 recordings that could be used for further analysis. As seen in Table 1, only a small minority of the subjects was able to accomplish the whole set of tasks. Moreover, a small
number of recordings could not be used because one of the observers did not give a score.

During the accomplishment of tasks the subjects phonated at freely chosen pitches. Phonations in a falsetto register were avoided, whenever possible. Table 2 gives the averaged fundamental frequencies and standard deviations for both women and men. The frequencies are in close range for each separate frequency level, with the exception of the phonation with low pitch at normal intensity level, which has a considerably higher frequency. Absolute values for sound pressure levels were not obtained due to the automatic gain control of the recording equipment.

Inter-observer reliability for rating the percentage of glottal closure was determined using Cronbach's $\alpha$, which ranges from 0, indicating no agreement, to 1, indicating complete agreement. A high level of agreement of $\alpha=0.93$ was established for rating glottal closure. The mean inter-observer correlation was 0.82. Intra-observer reliabilities were established with correlation coefficients. The correlation coefficients varied among the three observers from 0.63 to 0.98 (p<0.001).
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<tr>
<th>Intensity level</th>
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| Men             |       |        |       |
| Soft            | 36.55 | 15.38  | 25.98 |
| (19)            | (27)  | (27)   |       |
| Normal          | 9.65  | 19.34  | 19.94 |
| (36)            | (41)  | (38)   |       |
| Loud            | 2.12  | 2.38   | 8.30  |
| (21)            | (29)  | (29)   |       |

| Women           |       |        |       |
| Soft            | 20.00 | 24.44  | 23.92 |
| (10)            | (17)  | (14)   |       |
| Normal          | 12.85 | 13.22  | 20.97 |
| (19)            | (80)  | (77)   |       |
| Loud            | 5.09  | 5.35   | 14.89 |
| (18)            | (29)  | (28)   |       |

Table 1. Averaged percentage of glottal closure during phonatory tasks for men and women. The averaged percentage of closure varies between 68.6 to 99.3% in the men and between 45.1 and 96.5% in the women. The lowest values are found for phonation with high pitch and low intensity, and the highest values for phonation with low pitch and high intensity. There is a considerable difference in the magnitude of the standard deviations.

Table 2. Averaged frequencies in Hz produced during phonatory tasks for men and women. (/): standard deviations.

Table 1 gives the averaged percentage of closure for each intensity and frequency, separately for men and women. The averaged percentage of closure varies between 68.6 to 99.3% in the men and between 45.1 and 96.5% in the women. The lowest values are found for phonation with high pitch and low intensity, and the highest values for phonation with low pitch and high intensity. There is a considerable difference in the magnitude of the standard deviations.
deviation. The highest standard deviations are found for the low intensity levels, while there are relatively small standard deviations for the high intensity levels. This means that a large variety in percentage of glottal closure can be found at a low intensity level, whereas this variation is limited at high intensities.

To establish differences in glottal closure between men and women, as well as to determine the effects of frequency and intensity level, three way analysis of variance was performed. A significant difference was found between men and women (F(1,540)=49.16, p<0.001), with men showing a higher percentage of closure. Because significant differences were established between men and women and both intensity and frequency level (F(2,539)=3.96, p=0.02, and F(2,539)=7.82, p<0.01, respectively), the effects of these factors were separately analyzed for men and women with two way analysis of variance. Table 3 gives the analysis of variance summary table. No significant interaction between intensity and frequency level was found. In women a significant effect of both intensity (F(2,272)=46.77, p<0.001) and frequency (F(2,272)=21.67, p<0.001) was established, whereas in men only a significant effect of intensity (F(2,264)=31.00, p<0.001) was found. Glottal closure improves in both sexes with increasing intensity, and, specifically in women, with decreasing frequency.

**DISCUSSION**

Though incomplete glottal closure is described in a number of articles, specific information on the completeness of closure is sparse. Södersten et al.
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give quantitative descriptions of glottal closure on a discrete scale (1). Ratings of glottal closure using a percentage supply data that can be used to observe small changes in closure and to analyze the influence of variables such as vocal pitch and intensity. However, before introducing a new method to describe glottal closure the applicability and accuracy should be determined. In this study a high inter- and intra-observer reliability was established, giving evidence of the clinical practicability.

A feature of glottal closure not expressed in rating with a percentage is the location of the incomplete part. Most incomplete closures are located posteriorly, especially in women (1), whereas in men sometimes an unclosed glottis anteriorly can be seen (2). However, this absence of location of the glottal gap presents no obstacle in using the information on percentage in analyzing relationships with physiological variables and quantifying the robustness of the larynx.

Essential for an adequate assessment of glottal closure is the equipment used in visualizing the larynx. A 90° rigid endoscope with a powerful light source provides an undistorted and detailed laryngeal image. During phonation, stroboscopy shows vocal fold functioning and closure can be closely observed. The image obtained should be recorded in order to make it possible to analyze the images in more detail --if necessary in slow motion-- afterwards.

The percentage of glottal closure with standard deviations indicate that, especially in women at lower intensities, the majority of subjects do not have complete closure during phonation. This is in agreement with other studies giving information on the relative number of complete glottal closures among subjects (1,3,4).

The results of this study demonstrate better closure in men compared to women, as well as the specific influence of both pitch and vocal intensity on glottal closure. Better closure in men is in agreement with the results of Södersten et al. (1), who also reported a positive effect of vocal intensity on closure in both sexes, although in women this effect was not significant with a p-value (p=0.0106) slightly above their chosen level of significance (p<0.01). Although not significant, in women a negative effect of increasing pitch on glottal closure was also observed by Södersten et al., which confirms the
finding of the present study. The smaller number of subjects used in the study of Södersten et al. is presumably responsible for the fact that observed influences on glottal closure are not significant in all cases.

Because variations in vocal intensity and, to a lesser extent only in women, variations in pitch have a significant influence on glottal closure, the functioning larynx should not be evaluated at only one pitch and intensity level. Variation in pitch and intensity exemplifies the effect of vocal fold physiology on glottal closure. Extremes in phonatory conditions, that is loud phonation with normal or low pitch, in contrast to quiet phonation with high pitch, however, outline the anatomical restrictions of the voice source.

In clinical practice an almost complete glottal closure of at least 90% has to be observed during loud phonation in women, whereas this closure should be complete in men. If these specifications are not reached, it raises the presence of a less robust larynx, which is more susceptible to vocal complaints (5,6). Diagnosing a less robust larynx may therefore not only have consequences for voice entrance examinations to studies that require an optimal vocal apparatus of the candidate, regarding the intensive use of the voice (schools for singers, actors and speech therapists), but it can also lead to specific advice regarding choice of a profession. To distinguish a less robust larynx from a normal larynx, glottal closure should be judged at several intensities, from quiet to loud.

Potentially beneficial treatments for the less robust larynx are limited. This should be kept in mind while giving advise regarding the choice of profession. To promote a responsible voice use and to prevent secondary vocal fold abnormality, speech therapy is advised. During a limited number of sessions the patient can explore the limitations of his or her voice and learn to optimize voice possibilities. With the knowledge of the voice possibilities prolonged vocal hygiene is pursued, which helps to minimize voice strain and thereby the risk of vocal fold damage.

References

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