Gender differences in the realization of vowel-initial glottalization

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Abstract
The aim of the study was to investigate gender-dependent differences in the realization of German glottalized vowel onsets. Laryngographic data of semi-spontaneous speech were collected from four male and four female speakers of Standard German. Measurements of relative vocal fold contact duration were carried out including glottalized vowel onsets as well as non-glottalized controls. The results show that female subjects realized the glottalized vowel onsets with greater maximum vocal fold contact duration than male subjects and that the glottalized vowel onsets produced by females were more clearly distinguished from the non-glottalized controls.

Index Terms: glottalization, laryngograph, EGG, gender differences, German

1. Introduction
Glottalized vowel onsets are a well-documented and auditorily distinctive characteristic of German speech. The term ‘glottalized’ in this paper refers to an articulation which is thought to involve a constriction of the vocal folds, resulting in a deceleration or complete cessation of vocal fold vibration. Linguistically, glottalized vowel onsets in German function as optional boundary signals between morphemes and words, with stressed syllables showing glottalization more frequently than unstressed ones [1]. Acoustic studies have shown that glottalized vowel onsets in German as well as in other languages [2,3,4] can have a range of acoustic correlates, including apparent glottal stops and stretches of irregularity in fundamental frequency or amplitude. Several terms such as ‘creak’, ‘creaky voice’ ‘glottalization’ or ‘laryngealization’ have been used for stretches of irregularity in the speech signal, which include glottalization pertaining to speech sounds as well as other sources of irregularity such as hesitation phenomena or creaky voice at the end of utterances. For the study of gender-specific characteristics of speech production, glottalization phenomena are of interest as they result from adjustments of the vocal folds, i.e. from vocal organs in which gender differences are particularly apparent. However, no formal research has so far been published in this specific field.

The instrumental work for this paper was based on the Laryngograph, a device which monitors vocal fold vibration by measuring the changes of electrical impedance across the neck. For the analysis of glottalization in the Laryngograph signal, a measure was required which would accommodate cycle-to-cycle irregularity as well as signal diversity. One common method of examining vocal fold function from the Laryngograph signal is the application of a threshold-based contact quotient (CQ). This method appeared to be suitable for the present study, as its application does not rely on the location of glottal opening and closure events, which would appear problematic in regions of heavy irregularity. As the Laryngograph signal does not provide reliable information about glottal width but only about relative contact duration, the CQ serves as a relative measure. Glottalized vowel onsets, when compared with non-glottalized vowels, are expected to show an increase in vocal fold contact duration during individual cycles.

2. Method

2.1. Materials
The materials used included two utterances: the utterance sah eber [za/ˈtɛŋ] (‘saw rather’) in which a glottalized vowel-onset was expected at the beginning of the second word [ˈtɛŋ] as well as the utterance verleih nur [feɾˈlaɪ nuɐ] (‘lend only’) in which the diphthong [ai] served as the control item. The utterances were embedded in test sentences which were elicited through a ‘word game’ involving simple arithmetic tasks. The subjects were four male and four female adult speakers of Standard German who did not suffer from any speech impediments or voice disorders. Each subject recorded the two utterances 20 times each, while recordings were taken with the Laryngograph and an attached electret microphone. The Laryngograph signal (Lx) was then digitized for further processing in the SoundScope 16.1/3 software package.

2.2. Procedure
2.2.1 Removing a drifting baseline
Cycle-to-cycle fluctuation in period length and amplitude is a common characteristic of the Laryngograph signal during the production of glottalized speech sounds [5]. In addition, particularly in running speech, the Laryngograph signal often displays a drifting baseline, which may impede the location of signal minima and maxima required for calculating the CQ. A common method for removing the baseline drift is to apply a high pass filter either during the recording or at a later stage. However, while the high-pass filter removes the low-frequency component of the signal, it also affects the steepness of the rising and falling deflections of the individual cycles, depending on the cut-off frequency of the filter. The Laryngograph used in the present study has a pre-set high-pass filter of 6.125 Hz, which means the rising and falling deflections may be limited while the baseline drift can still be significant.

In order to achieve a steady baseline whilst maintaining the shape of the Lx waveform, an alternative method was used. First, the difference between the values of two neighbouring signal minima (points a and b in figure 1) was measured (distance d). Then the section of the wave between the two minima (c) was re-written, with each point in the section being vertically displaced by the exact amount that was required to successively compensate for the measured distance d. Figure 1 shows an example of an original Lx form along with a corrected waveform. It is apparent that the signal minimum b
as located in the original waveform in figure 1 had been shifted to the right through the drifting baseline and that the corrected waveform would allow for more accurate measurements. This procedure was carried out over the relevant regions in the Lx waveform.

2.2.2 Calculating the CQ

The next step in the analysis was to calculate the CQ for each vibratory cycle in the corrected wave. The calculation was achieved by locating two neighboring signal maxima (points \(a\) and \(c\) in figure 2) as well as the signal minimum between the two points \((b)\). The distance between points \(a\) and \(d\) represents the relative contact duration (RCD), which is the time during which the signal falls from its maximum to 25 per cent of cycle amplitude (see also figure 3). The CQ is calculated by dividing RCD by period length and multiplying it by 100. In this example, the result is a CQ of 40.

A common problem with analyzing Lx signals of glottalization is that period length as well as amplitude can fluctuate significantly, which means that automatic tracking and reading of signal minima and maxima is sometimes difficult or impossible. For this reason, in regions of strong fluctuation the locations of signal minima and maxima were identified semi-automatically. First the approximate location of minima and maxima was identified manually, then the exact location was calculated by the SoundScope software and the values were read. After the CQ was calculated, its value was plotted over the corresponding cycle from one signal maximum to the next, as can be seen in figure 4. The signal in this figure is taken from a glottalized vowel onset of a female speaker producing the utterance *sah eher* [za: \(\text{#/uni02D0 /uni02C8/uni0294e/uni02D0/uni0250}\) (‘saw rather’). Vocal fold vibration at the glottalized onset of [\(\text{#/uni02C8/uni0294e/uni02D0/uni0250}\)] decelerates rapidly and the durations of glottal cycles increase, with the CQ reaching a maximum value of 86.8.

Figure 4: Laryngograph signal and CQ plot of a glottalized vowel onset of a female speaker in the utterance *sah eher* [za: \(\text{#/uni02D0 /uni02C8/uni0294e/uni02D0/uni0250}\) (‘saw rather’)

Figure 5 shows a glottalized vowel onset produced by a male speaker displaying a noticeably different vibratory pattern. In this case, the Laryngograph signal shows a rapid decrease in amplitude and cycle-to-cycle fluctuation, while the CQ first rises slightly but then shows substantial decreases with...
individual cycles. The highest CQ achieved in this case was 60.

Figure 6 represents the Laryngograph signal and the CQ plot of a control item, i.e. the diphthong [ai] in *verleih nur* [fɐ̝'laʊ nuɐ̝] (‘lend only’) produced by a female speaker. The Lx signal is comparatively regular in period length and amplitude, while the CQ shows a small increase towards the centre of the diphthong which reaches a maximum CQ value of 44.

2.2.3 Data extraction

After the CQ values were plotted, data were extracted for further analysis as follows. When the CQ trace showed a peak in the relevant region, the highest CQ value was located and its value was read. When the CQ trace did not show a clear peak, a spectrogram of the speech signal was used in order to either locate the boundary between the vowels [a] and [ɛ] in [za ˈɛtɛ] or to locate the midpoint of the diphthong [ai] in [fɐ̝'laʊ nuɐ̝] in the controls. The corresponding value of the CQ trace was then read. This way, each item was represented by one CQ value, meaning that for each of the eight subjects, 20 values represented the sample of glottalized vowel onsets and 20 values represented the sample of controls.

3. Results

Figure 7 represents a box plot of the CQ values for the glottalized vowel onsets and the controls for the four male and the four female subjects. For each subject the values of the glottalized vowel onsets were higher than the values of the controls, which suggests that the glottalized vowel onsets were produced with longer vocal fold contact duration. An independent samples t-tests carried out for each subject showed that the difference between the mean of the CQ values for glottalized vowel onsets and the mean of the CQ values for non-glottalized vowels was significant in each case (p<0.01).

The second finding apparent in the box plot is that all female subjects produced the glottalized vowel onsets with higher maximum CQ values than the male subjects, which suggests that relative vocal fold contact duration was higher with the female than the male subjects. A further independent samples t-test was carried out, this time to compare the glottalized vowel-onsets produced by males with the ones produced by females. The t-test showed again that the difference between the two means (55.8 (SD8.527) for the males and 74.6 (SD11.881) for the females) was significant (t(143.305) =11.494, p<0.01). While the CQ values of the non-glottalized vowels do not appear to differ much between the male and the female subjects, the CQ values of the glottalized vowel onsets produced by females are higher, showing the female subjects to distinguish more clearly between the presence and absence of glottalization.

4. Discussion

One possible explanation for the observed gender differences may lie in the anatomical differences between the male and the female vocal fold. The smaller mass, i.e. the lower length and thickness of the female vocal fold when compared with the male vocal fold, may facilitate a rapid deceleration or interruption of vocal fold vibration.

Another factor which may have to be considered is the glottal setting required for the production of glottalized speech sounds. According to Ladefoged [6], the production of creaky voice requires the vocal folds to be thick, bunched and shortened, with only the anterior part of the glottis vibrating. A comparison between the functional structures of the male and the female vocal fold showed that in females the posterior glottis accounts for 42% of the total glottic length while for males it is 37% [7]. This would mean that a constriction of the posterior glottis in females may leave a smaller proportion of the anterior glottis still vibrating, which may account for the greater difference between modal voicing and glottalization in females.

On the other hand, sociophonetic factors may have to be taken into account when considering possible causes for the observed gender differences. Several phonetic studies on male and female vowel productions in different languages have suggested that females tend to show a greater distinction between vowel qualities and vowel lengths than males, which may be interpreted as female speech displaying greater clarity [8]. As the glottalization of vowel onsets is a marker of word and morpheme boundaries, an enhanced articulation of this type of vowel onset may then be interpreted as a way of achieving greater clarity in speech. Further research, in
particular the investigation of possible gender differences of glottalization phenomena in other languages would be required to gain a better understanding in this field of research.

5. References