Acoustic Correlates of Glottal Opening in German Obstruent Production

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ABSTRACT

For the first five vowel periods after aspirated/voiceless and unaspirated/voiced stops/fricatives in German the degree of glottal opening based on transillumination was measured simultaneously with the acoustic voice quality parameters H1-H2, H1-A1, H1-A3 (in order to capture breathy phonation and glottal leakage) and with f0. A gradual decrease in glottal opening and the voice quality values was observed after aspirated stops and voiceless fricatives, usually with an earlier-timed reduction in the case of the fricatives than the stops. Slight glottal opening and vq-value reductions were observed after unaspirated stops, probably resulting from aerodynamically-conditioned passive glottal opening. Higher vq-values were found after voiced fricatives than unaspirated stops. This is hypothesized to be a consequence of increased glottal leakage due to vocal fold slackening employed to maintain obstruent voicing, which in German is phonologically required for voiced fricatives such as /v/ but not for unaspirated stops such as /b/.

1. INTRODUCTION

The production of aspirated stops and voiceless fricatives in languages like English, Swedish, and German leads to certain amounts of breathy phonation in the adjacent vowels [e.g. 1,2,3,4,5,6]. It is commonly assumed that aerodynamic indices of breathy voice such as high open quotient [1,2] or acoustic indices such as high H1-H2 or H1-A1 [3,4,6] in vowels preceding or following aspirated stops and voiceless fricatives are a coarticulatory effect that is due to the fact that glottal abduction can begin before vowel offset and glottal adduction can end after vowel onset, respectively. Yet, there is very little empirical data available where glottal opening and voice quality induced by obstruents have been compared directly [cf. 1]. In the present study glottal opening behavior and acoustically measured voice quality are studied at the onset portion of vowels following aspirated stops and voiceless fricatives. By comparing these groups of sounds it is possible to investigate how coarticulatory voice quality is influenced by patterns of oral-laryngeal coordination. For example, it is shown by [1] that after voiceless fricatives breathy voice reduces sooner than after aspirated stops. They explain this result by the fact that the glottal opening gesture is coordinated earlier with respect to vowel onset in voiceless fricatives than aspirated stops, hence leading to earlier termination of glottal adduction. The glottal opening and voice quality behavior of aspirated stops and voiceless fricatives are also compared to the influence of the unaspirated stop and voiced fricative cognates. Less dramatic voice quality changes are expected with these sounds, since glottal opening is probably very small at best. However, it is possible, that some amount of glottal opening is induced passively due to aerodynamic factors [9] and that small glottal abductions of this kind influence the voice quality early in the following vowel. Another possibility is that physiological settings required to enhance voicing in obstruent production have an influence on voice quality. One hypothesis to be investigated in particular is that vocal fold slackening, which enhances obstruent voicing, leads to a certain amount of glottal leakage that coarticulates into the following vowel.

2. METHOD

A set of words containing the aspirated stops /p,t/ and the unaspirated stops /b,d/, as well as the voiceless fricatives /f,s/ and voiced fricatives /v,z/ were produced by a male speaker of German. (In German the phonemic distinction between /p,t/ and /b,d/ is more consistently and saliently implemented as aspirated vs. unaspirated than as voiceless vs. voiced, respectively; cf. [6].)

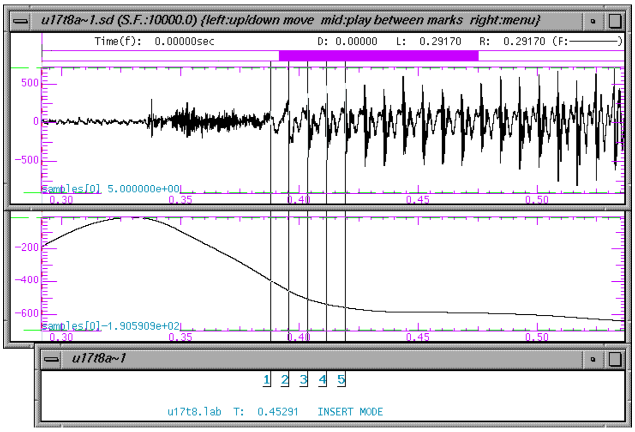

Figure 1: Audio waveform (upper signal display) and smoothed transillumination signal (lower signal display) at boundary between /p/ and /i/ with labels for the first five vowel periods (lowest window).

The target obstruents occurred in two types of context, word-medial position between stressed and unstressed

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vowel and word-initial position before stressed /i/ preceded by a carrier word ending in a vowel, and were produced about 20 times each in both contexts. Transillumination (TI) was used to study glottal opening behavior in obstruent production [cf. 6 for more details and data involving the TI recording on which this study is based; the present results are from the first recording session]. For each of the first five vowel periods after the target obstruent fundamental frequency and voice quality were measured in the audio signal, and for the same five temporal locations glottal opening degree was measured on the basis of the smoothed TI curve (see Fig. 1). The voice quality parameters investigated are H1-H2, H1-A1, and H1-A3 (amplitude of first harmonic minus amplitudes of second harmonic, first formant, and third formant, respectively). They were measured on the basis of DFT spectra with a 25.6 ms Hamming window centered around each of the five vowel periods. H1-H2 and H1-A3 were chosen because high values of these parameters are known as correlates of breathy voice or glottal leakage [e.g. 7]. Physiologically, high H1-H2 is a correlate of high open quotient, and high H1-A3, as a measure of increased spectral tilt, reflects a closing portion of the glottal cycle of relatively long duration and reduced skewness [8]. H1-A1 was included because this parameter has been used successfully in some relevant studies [3] and because it has been claimed that H1-A1 is a correlate of glottal opening degree [8]. Indeed, correlations between degree of glottal opening and the three voice quality parameters, calculated word-medially across aspirated stops and voiceless fricatives and across all five vowel periods, turn out to be slightly higher for H1-A1 (0.785) than for H1-H2 (0.766) and lowest for H1-A3 (0.638). Corrections proposed by [7,8] (H1*-H2*, H1*-A1, H1*-A3*) were applied but the resulting obstruent-induced patterns differ only little from those of the uncorrected voice quality values. Furthermore, H1*-H2* could not be determined for the vowel [i]. For these reasons only the results for uncorrected H1-H2, H1-A1, and H1-A3 are reported.

3. RESULTS

Unless mentioned otherwise the results presented in this section are from word-medial position. In most respects the patterns in word-initial context are essentially the same. Fig. 2 (top graph) shows that after the aspirated stop there is a gradual decline in glottal opening from vowel onset until (at least) the fifth period, indicating the final stages of the glottal opening gesture associated with stop aspiration. Glottal opening of the unaspirated stop is significantly lower than after the aspirated stop for all periods except the final one. Even the unaspirated stop shows a slight decrease in glottal opening, probably resulting from slight passive glottal abduction induced by buildup of intraoral air pressure [cf. 9]. The three voice quality parameters H1-H2, H1-A1, and H1-A3 show quite a similar pattern as the glottal opening gesture, with a gradual lowering of values – indicating decreasing levels of breathy voice into the vowel – and with higher values after the aspirated than the unaspirated stop.

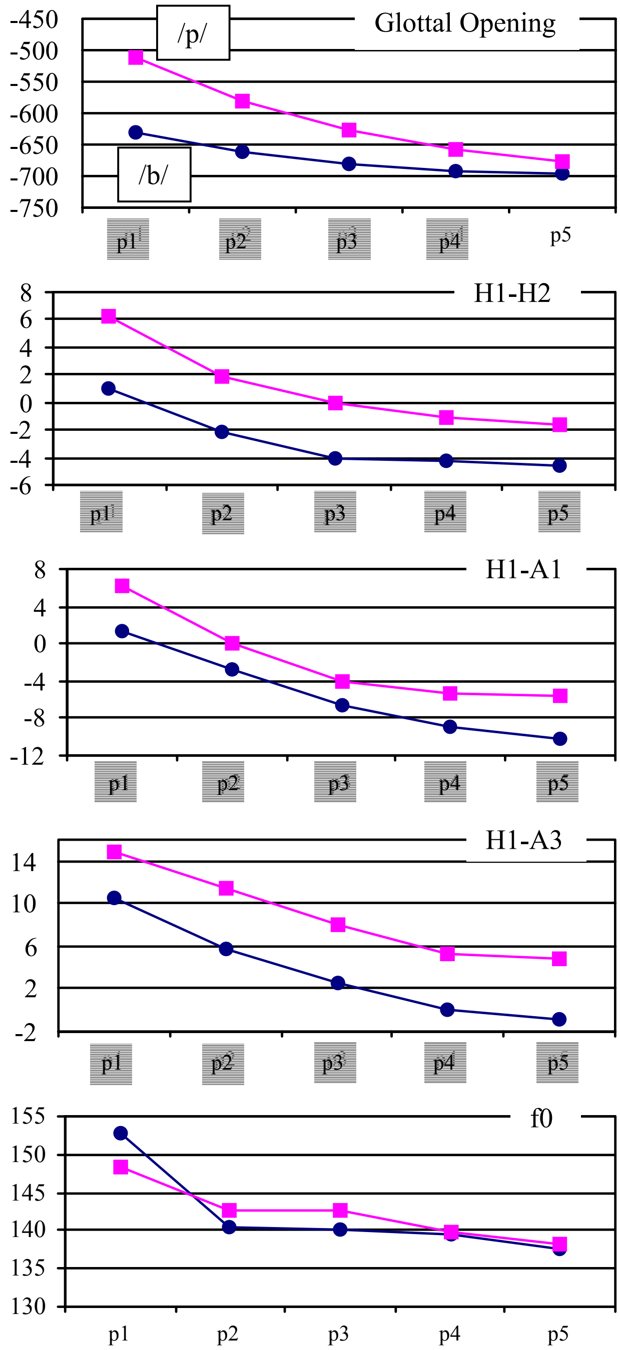

Figure 2 (from top to bottom): Glottal opening (y-axis in arbitrary units), H1-H2, H1-A1, H1-A3 (y-axis in dB), and f0 (in Hz) for first five periods (x-axis) into unstressed schwa after aspirated (gray squares) and unaspirated (black circles) labial stop (average across about 20 repetitions). Periods with significant aspirated-unaspirated differences ($p < 0.05$) are marked by gray shading.

These glottal opening and voice quality dynamics after aspirated and unaspirated stops in German are consistent with the results on German by [3; see their Fig. 9, whereby L0=H1 and L1=A1] and with the results on the Swedish and most of the English speakers reported in [1, 2; see in particular the TI data in 1 and the open quotient data in 1,2].

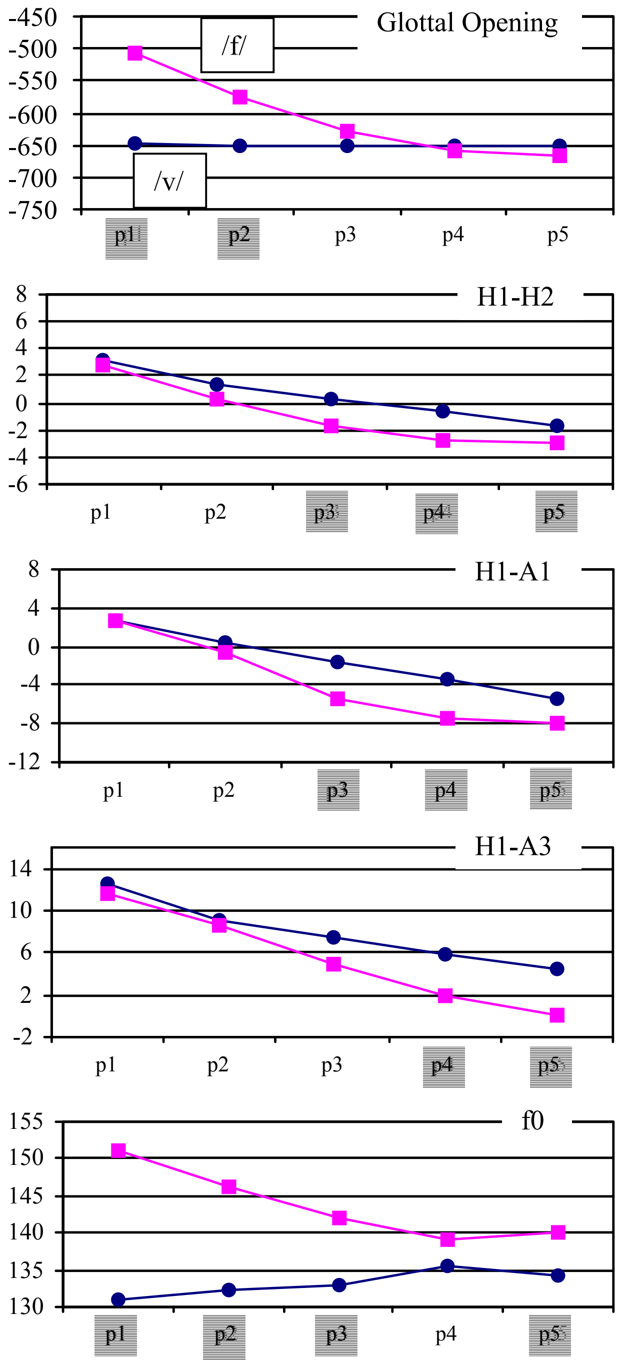

Figure 3 (from top to bottom): Glottal opening, H1-H2, H1-A1, H1-A3, and f0 for first five periods into unstressed schwa after voiceless (gray squares) and voiced (black circles) labial fricative (cf. Fig. 2 for further conventions).

Fig. 3 shows the situation after the labial fricative. The glottal opening pattern after the voiceless fricative is the same as after the aspirated stop. The three voice quality parameters also show a similar gradual decrease as after the aspirated stop, but they begin and end at lower values. Lower H1-H2 after voiceless fricatives than aspirated stops is consistent with the open quotient measurements of [1]. But in this case it cannot be explained by oral-laryngeal coordination (cf. Section 1), since the glottal opening pattern is practically the same. However, a different situation occurs when comparing aspirated stop and fricative at *alveolar* place of articulation. In that case, not only H1-H2 but also glottal opening decreases sooner after the fricative than the stop, which is shown in Fig. 4. Lower H1-H2 after /s/ than /t/ is also found in English [4] and German [evaluation of raw data in 6].

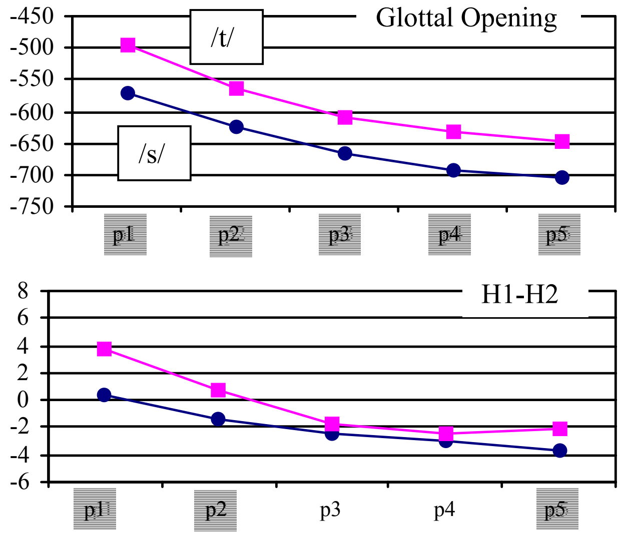

Figure 4: Glottal opening (upper) and H1-H2 (lower) for first five periods into unstressed schwa after aspirated alveolar stop (gray squares) and voiceless alveolar fricative (black circles) (cf. Fig. 2 for further conventions).

The most striking difference between stops and fricatives, as shown in Figs. 2,3, is in terms of the unaspirated/voiced category (/b/ compared to /v/). Whereas there is a gradual decrease in glottal opening after the unaspirated stop, glottal opening stays roughly constant after the voiced fricative at the high level found at the first period after /b/. After the first period glottal opening becomes higher after /v/ than /b/; this difference is statistically significant from period 3 to 5. Even more striking is the difference in terms of voice quality. Statistical comparison between the influence of /b/ and /v/ shows that H1-H2, H1-A1, and H1-A3 is significantly higher after /v/ than after /b/ (for H1-H2 this significant difference occurs with all five periods, for H1-A1 and H1-A3 it occurs from p2 to p5). Figs. 2,3 show that as a consequence of these high values after /v/, H1-H2, H1-A1, and H1-A3 are higher after /v/ than after /f/ beginning with the second period and significantly so from p3 to p5 (except for non-significant H1-A3 at p3). An explanation for these differences between /v/ and /b/ might derive from the phonological status of German obstruents. As addressed in [6], /b,d,g/ are often produced with no or little voicing during closure. While most frequently the case after pause or voiceless sounds, this voicing instability in /b,d,g/ has also been observed for German in intervocalic word-medial context, where voicing often ends well before the end of closure. The fricative /v/, on the other hand, is most commonly fully voiced in this position (generally also /z/, but with more cases of partial devoicing). It is argued in [6] that the feature [voice] is phonologically active in German

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fricatives but not in its stop system (where [tense] or [spread glottis] is the only distinctive feature). It follows from this analysis that the speaker should make a physiological effort to ensure voicing in /v/ but not in /b/ (where closure voicing, to the extent it appears, results more passively due to aerodynamic constellations). One of these physiological strategies to enhance obstruent voicing (along with tongue root advancement, etc.) is to slacken the vocal folds [10]. That the vocal folds were in a more slack configuration with /v/ than /b/ in this study is supported by the f0 patterns shown in Figs. 2,3, where after /v/ f0 rises from a comparatively low onset value whereas after /b/ f0 falls from a high onset value. Slackening the vocal folds, in turn, might lead to a certain amount of glottal leakage, causing a slight degree of breathy voice as a coarticulatory effect on the following vowel. This would explain the comparatively high values of H1-H2, H1-A1, and H1-A3 after /v/. The higher glottal opening values after /v/ than /b/ could also be explained in this manner. However, this glottal opening behavior is not stable across contexts. In contrast to word-medial position, discussed so far, in word-initial position glottal opening is significantly higher after /b/ than /v/ for all five periods. Yet, the three voice quality parameters show essentially the same behavior in word-initial as in word-medial position (higher after /v/ than /b/). Also the f0 patterns are essentially the same in both contexts. It appears that the speaker wants to ensure voicing of /v/ in word-initial as much as in word-medial position by producing slack voice and hence increasing glottal leakage, but measurements of glottal opening degree do not detect this increase in glottal leakage and instead seem to be more sensitive to the passive glottal abduction effect that was mentioned above, which is probably stronger in /b/ than /v/ (due to expectedly higher intraoral air pressure buildup in /b/ than /v/). The observation that H1-H2 is higher after /v/ than /b/ is consistent with [1,2], where for most of their English speakers open quotient in the early periods of the second vowel in /ava/ is higher than in /aba/. Along similar lines, [5] report higher spectral tilt (corresponding to H1-A3) in vowels after /z/ than /d/ in English (though open quotient was found by them to be essentially the same). Higher open quotient associated with /v/ than /b/ was often found to occur also in the *preceding* vowel [1,2]. These speakers, who showed an increase in open quotient towards the end of the vowel preceding /v/, must have actively planned the shift from a more modal to a more slack and leaky voice quality in the upcoming voiced fricative [cf. 10, p. 484]. This analysis of a planned shift from the voice quality in vowels to a different voice quality that is suitable for maintaining voicing in the following obstruent goes back to [11]. The high values of H1-H2 etc. found with /v/ in this study seem to show that phonologically required obstruent voicing can lead to an actively controlled adjustment of voice quality.

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