Voice and aspiration in German and East Bengali stops: A cross-language study

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Abstract

This production study investigates temporal and F_0 cues (closure duration, release duration and F_0 perturbations of the following vowel) in respect to voice and aspiration in German and East Bengali geminate stop consonants. The objective is to compare the stops of the two languages according to their phonetic correspondence on the one side and to their phonological correspondence on the other. The results of the phonetic comparison show that the German and East Bengali stops behave analogically for closure duration and release duration, while phonologically there are some differences for these temporal properties. The F_0 analysis revealed different curves for the stops of the corresponding phonetic classification but similarity for stops of the same phonological classification. The latter findings suggest that speakers actively adjust or influence F_0 height, in order to match it to the stop's phonological classification in the particular language.

1. Introduction

The acoustic realization of the phonological feature voice of oral stops is manifested differently across languages. While in most languages, it is primarily the presence versus absence of prevoicing or glottal buzz during closure duration that marks the difference, there are other languages, which realize the same contrast through the presence or absence of aspiration during the phase of release. This is the case, for instance, in German and English, where voiceless stops in syllable initial and prestressed position have a long release duration, that generally goes hand in hand with considerably strong aspiration. The corresponding voiced counterparts, however, have a relatively short release duration (with little or no aspiration). In contrast, Bengali or Hindi stops are categorized by voice and aspiration. As mentioned above, here voice is marked by the presence or absence of glottal buzz during closure, and aspiration by the presence or absence of high frequency noise after release. Hence, Bengali and Hindi display a four-way contrast of voiceless unaspirated, voiceless aspirated, voiced unaspirated and voiced aspirated oral stops, while German only displays a two-way contrast of voiced versus voiceless stops. The phonetic contrast of voiceless aspirated versus voiceless unaspirated in German is interpreted as being phonologically a contrast of [-voice] versus [+voice] respectively. In Bengali, however, the same phonetic contrast is phonologically interpreted as [+aspiration] versus [-aspiration] within the category of voiceless stops (see Table 1 for illustration).

Besides the primary acoustic cues for the distinction of voice (e.g. length of release duration, strength of aspiration, presence or absence of prevoicing or glottal pulsing during closure), there are secondary cues such as the fundamental frequency perturbations (F_0) at the beginning of the following vowel that also contribute to this contrast. (For a detailed listing of all the acoustic properties involved cf. [1]). Several production studies have found, that F_0 for voiceless stops starts relatively high and is generally followed by a rapid steep fall. F_0 onset for voiced stops has been observed to be low (in relation to that of voiceless stops) with a following rising, level or even slightly falling contour [among others 2, 3, 4, 5, 6].

The current study investigates the role and relation of the two temporal parameters closure duration (CD) and release duration (RD) as well as the behavior of the F_0 parameter in respect to voice and aspiration of German and East Bengali oral stops. We intended to compare the stops of both languages on the basis of (a) their corresponding phonetic categories and (b) their corresponding phonological categories.

2. Experiments

2.1. Stimuli

The tested phonemes in both languages were intervocalic geminate stops ($VC_{\alpha}C_{\alpha}V$). (A geminate denotes a long consonant. In German and Bengali, the phonetic correlate of a geminate stop is a long closure duration as compared to a relatively short closure duration, which classifies a singleton or short stop consonant [7, 8, 9]. In Bengali phoneme quantity is a distinctive underlying contrast of the language, while in German, geminates can only be obtained by the process of assimilation [7, 8].) Place of articulation was labial and coronal. (In German, coronal stops are alveolar and in Bengali they are dental. Moreover note that Bengali has no voiceless aspirated labial stops). Table 1 lists the investigated phonemes. In German, the vowels following the crucial segments were [a, ʊ, ɔ ɪ, uː] equally distributed across the voice category. In Bengali, the following vowels were [a, ɔ, o, e, æ].

Table 1: Investigated phonemes, including their corresponding phonetic and phonological assignments (*voi* = voice; *as*p = aspiration).

	East Bengali				German	
Phonetic classif.	[pː] [t̪ː]	[t̪ʰː]	[bː] [dː]	[bʰː] [dʰː]	[pː] [tː]	[pʰː] [tʰː]
Phonol. classif.	[-voi]		[+voi]		[+voi]	[-voi]
	[-asp]	[+asp]	[-asp]	[+asp]		

In Bengali five different words were chosen for each of the phonemes. The material consisted of 30 disyllabic, 4 trisyllabic and 1 four-syllabic word. The crucial segments always marked the onset of the second syllable. Standard word stress in Bengali is assigned to the initial syllable [10]. The total of the 35 Bengali stimuli were tested with one female and two male native speakers of East Bengali in four repetitions.

The German material consisted of 24 trisyllabic words (prefix+verb$_{inf}$). The prefix *ab-* was combined with 6 verbs beginning with a voiceless labial stop and another 6 verbs with an initial voiced labial stop. (The contact of the two place identical stops at the morpheme boundary led to regressive assimilation of the feature voice and thus resulted in voiced and voiceless labial geminates.) The voiced and voiceless coronal geminate stops were created analogically, by the same number of prefix+verb$_{inf}$ combinations with the prefix *mit-*. Main stress was, like in Bengali, on the second syllable of the word. The German stimuli were tested with two female and two male native speakers in three repetitions.

2.2. Measurements

All data were analysed for closure duration (CD), release duration (RD) and fundamental frequency of the following vowel (F_0), as defined below:

CD: The beginning of the closure was taken at the point where a sudden drop of amplitude was observed with a disappearance of the higher harmonics of the preceding vowel. The end of the closure was identified as the beginning of the release burst.

RD: The beginning of the release was marked by the first burst at the end of the closure. The end of the release was marked, where the first regular glottal pulses of the following vowel appeared in connection with a rising amplitude.

F_0: Pulse marks for the first six glottal pulses were added (manually set with a semi-automatic assistance of the Multi-Speech-program) at the relevant points of the signal - starting at the onset of regular glottal pulsing after the release. The duration of each pulse was converted into frequency. By connecting the frequency values, a curve is obtained which shows the changes of fundamental frequency from one glottal pulse to the next.

It should additionally be noted that none of the German voiced geminates showed voicing during closure. Like with the voiceless cognates, glottal buzz ceased shortly after oral closure. The same was the case for the Bengali voiceless geminates. The voiced ones, however, had either voicing throughout the whole length of the closure or at least until shortly before release.

2.3 Results and discussion

2.3.1 Closure duration

An ANOVA was performed with the following design and factors: *language* (German, Bengali), *aspiration* (aspirated, unaspirated), *language* (nested under *subjects* and set as a random factor), *language* crossed with *aspiration*, and *language* & *aspiration* (nested under *voice*).

Aspiration produced an overall significant effect [$F(1,691) = 147.6$; $p \leq 0.0001$] with the closure of the aspirated stops being shorter (162ms) than that of unaspirated stops (186ms). The interaction of *language* and *aspiration* was also significant [$F(1,691) = 15.2$; $p \leq 0.0001$] but the aspirated (short closure) – unaspirated (long closure) relation was the same in both languages, only the values being in different ranges: For Bengali the Least Square Mean (LSM) values were 168ms and 200ms for the aspirated and unaspirated stops respectively and in German this relation was 155ms to 172ms. A post hoc test revealed that the difference in each language was significant [$p \leq 0.0001$ for both Bengali and German]. Another significant effect was obtained for the interaction of *voice*, *language* and *aspiration*. If the stops of the two languages are compared on the basis of their phonological classification, we see that the relation of voiced and voiceless stops in German is reverse to that of the Bengali ones (cf. Figure 1). Voiced stop geminates in German have a longer CD than voiceless ones but the opposite is true for Bengali. A post hoc test showed that all three contrasts were significant [for German voiced-voiceless, Bengali voiced-voiceless (unaspirated) and Bengali voiced-voiceless (aspirated): $p \leq 0.0001$]. The German results are insofar striking, because it has been established by [11] for intervocalic singletons, that voiceless stops have a longer CD than voiced stops. The same relation has been found in various other languages [12, 13]. The reason for this divergence could be that in the German data, the geminates were produced by assimilation, while in Bengali all geminates were underlying tautomorphemic and hence lexical.

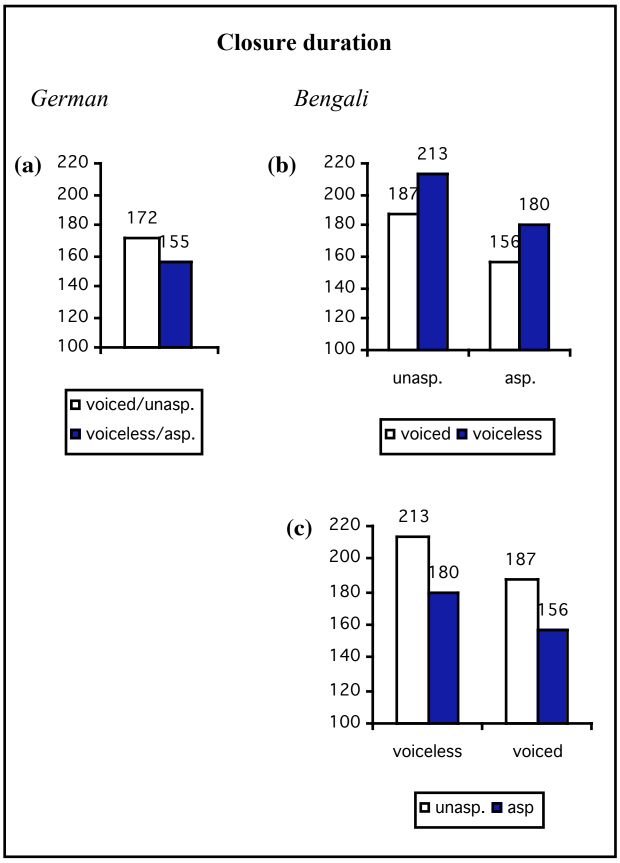

Figure 1: Comparison of closure durations (Least Square Means in msec) on the phonological level – (a) against (b), and on the phonetic level – (a) against (c).

2.3.2 Release duration

In the analysis of RD, the same ANOVA design was used as described above for CD.

Aspiration produced a significant effect [$F(1,691) = 1151.9$; $p \leq 0.0001$] with the RD of the aspirated stops being considerably longer than that of the unaspirated ones. The interaction between *language* and *aspiration* was not significant. Both in German and in Bengali, the relation and the values of the RD were approximately the same (LSM's German: aspirated = 44ms, unaspirated 13ms; LSM's Bengali: aspirated = 47ms; unaspirated = 18ms.) The interaction between *voice*, *language* and *aspiration* was again significant. A comparison on the basis of voice shows that in Bengali, there is a significant contrast only within the category of aspirated stops [post hoc test: p≤0.0001], with the voiceless ones having a longer RD than the voiced ones. This relation is the same as we find it for our German stops. Within the Bengali category of unaspirated stops, however, the voice distinction for RD is neutralized (cf. Figure 2). The RD values of the Bengali voiced and voiceless unaspirated stops are both in the range of the German voiced stops.

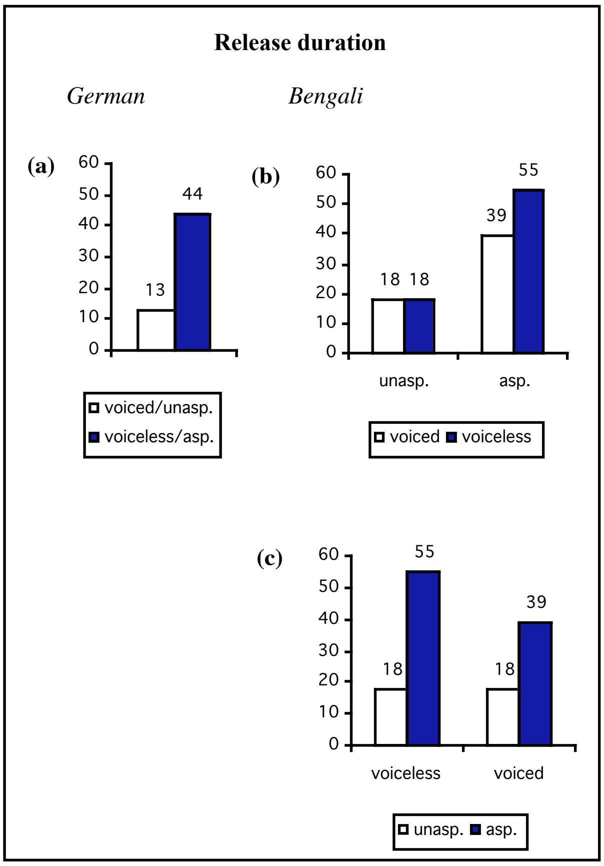

Figure 2: Comparison of release durations (Least Square Means in msec) on the phonological level – (a) against (b), and on the phonetic level – (a) against (c).

In Bengali, a RD contrast in respect to voice is (at least theoretically) not necessary, since, as mentioned earlier, this contrast is primarily realized through the presence and absence of glottal buzz during closure. This circumstance is reflected in the equal LSM values of the voiced and voiceless unaspirated stops. However the contrast does emerge in the group of aspirated stops.

2.3.3 F_0 perturbations

An ANOVA was performed with a complex design using the following factors: *language* (German, Bengali), *aspiration* (aspirated, unaspirated), *gender* (male, female), *glottal pulse* (1, 2, 3, 4, 5, 6), *subjects* (G1, G2, G3, G4, B1, B2, B3 – included as a random factor) and *voice* (voiced voiceless).

The differences and similarities between the two languages emerged most transparently in the significant interaction between *voice*, *language*, *aspiration* and *pulse* [F(12,4134) = 26.2; p≤0.0001)]. In terms of a comparison between the corresponding phonetic categories, the curves for the two languages are clearly different (compare Figure 3a to 3b). In German, the curve of the aspirated voiceless stops is higher than that of the unaspirated ones and is clearly separated from it. A post hoc test showed that the differences between each of the six glottal pulses is significant. [For the pulses 1 through to 6: p≤0.0001)]. In Bengali, the picture is different: The contrast between the first pulses is also significant [p≤0.028], but in the reverse order. F_0 of the voiceless aspirated stops lies below that of the corresponding

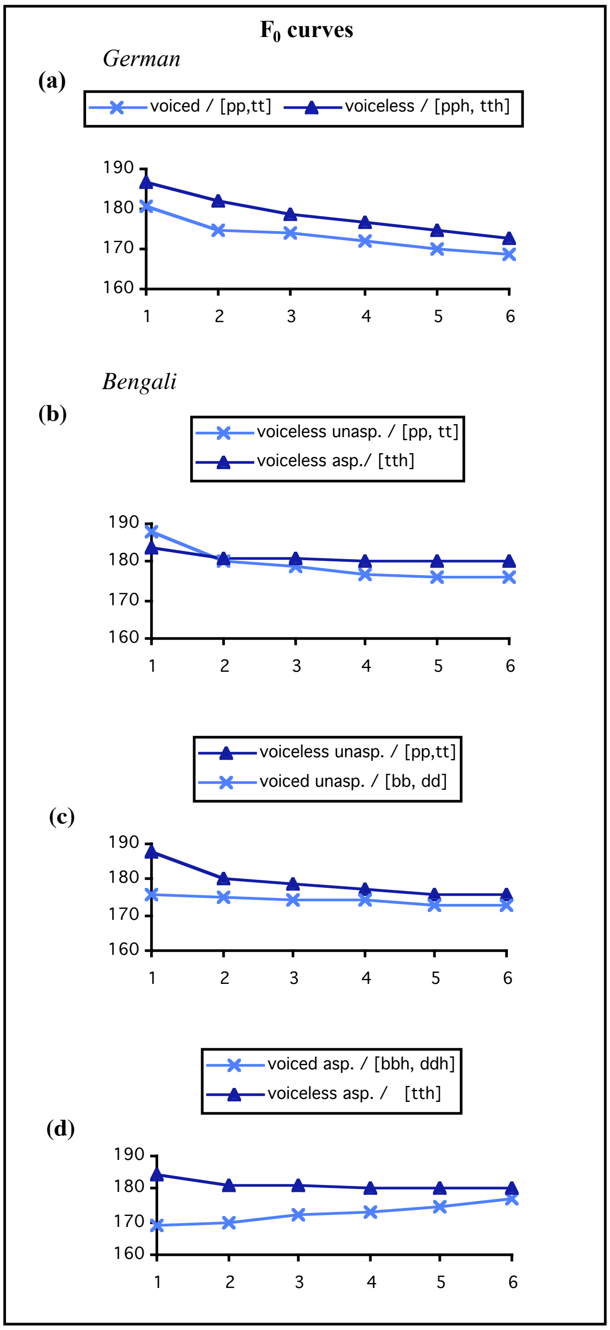

Figure 3: F_0 curves of the first six glottal pulses of the following vowel. The values of the ordinate indicate the Least Square Means in Hertz.

unaspirated ones. During the next three pulses (2, 3 and 4) the two curves more or less merge, and the differences are no longer significant. At pulse no. 5 and 6 the curves separate again [5: $p \leq 0.016$; 6: ≤ 0.010], and here, F_0 for the voiceless aspirated stops is, like in German, located above that of the unaspirated ones. If, however, the F_0 curves of the two languages are compared according to the phonological classification of the stops, the curves of the [-voice] stops are always above that of the [+voice] stops (compare Figure 3a to 3c and 3d). Given these differences and similarities of F_0 according to the phonetic and phonological assignment of the stops, we infer that the F_0 perturbations are not a pure 'automatic' consequence of aerodynamic and/or vocal fold tension factors. (For a discussion of the processes that are assumed to underlie or influence the F_0 perturbation see [4, 14, 15].) We hypothesize, that in addition to the 'natural acoustic correlations' of F_0 height, the phonological classification plays a mayor role in assigning a high or low F_0 to a given phoneme. A similar suggestion has been made by [5]. Consequently, we assume that the speakers are able to 'deliberately' manipulate F_0 height in order to match it to the phonological system of the individual language. Then again, if F_0 was influenced by purely 'automatic' factors, we would expect the curves of the German and Bengali voiceless aspirated and voiceless unaspirated stops to be more or less similar – but the opposite was found in this study. The current data suggest that the phonology of German and Bengali assigns a high F_0 to stops that are classified as [-voice] and a low F_0 to those that are classified as [+voice]. Moreover, in the phonology of Bengali, the system assigns an initial low F_0 to the stops that are classified as [+asp] and in the follow up, F_0 merges with those stops that are classified as [-asp].

3. Conclusions

If compared phonetically, closure duration (CD) is longer for unaspirated stops than for aspirated stops in both Bengali and German. In terms of release duration (RD), the relations are again the same across both languages, with the aspirated stops having a longer RD than the unaspirated ones.

The phonological comparison, however, revealed some differences. In Bengali CD was longer for the voiceless stops than for the voiced ones, while the reverse was the case in German. It was argued that the different geminate status of the two languages (German has derived geminates, Bengali has underlying geminates) could be a reason for the diverging results. The RD relation was the same for the German stops and the Bengali aspirated stops, with a higher value for [-voice] than for [+voice]. However in the case of the Bengali unaspirated stops no such relation in respect to voice was found: RD of the [+voice] and [-voice] stops was identical.

In terms of F_0, the curves of both languages showed the same trajectories when compared for the phonological feature voice: The curves of the [-voice] stops were always above those of the [+voice] stops. The comparison on the phonetic base, however, showed that the curves of the corresponding German and Bengali stops were not identical. These results raise the question about the factors involved in the production of the F_0 perturbations. Our findings suggest that speakers are able to 'actively' manipulate the F_0 contours – at least within a certain range – in order to express or support a particular phonological relation.

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